SEPTEMBER 1960

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. . . page 63

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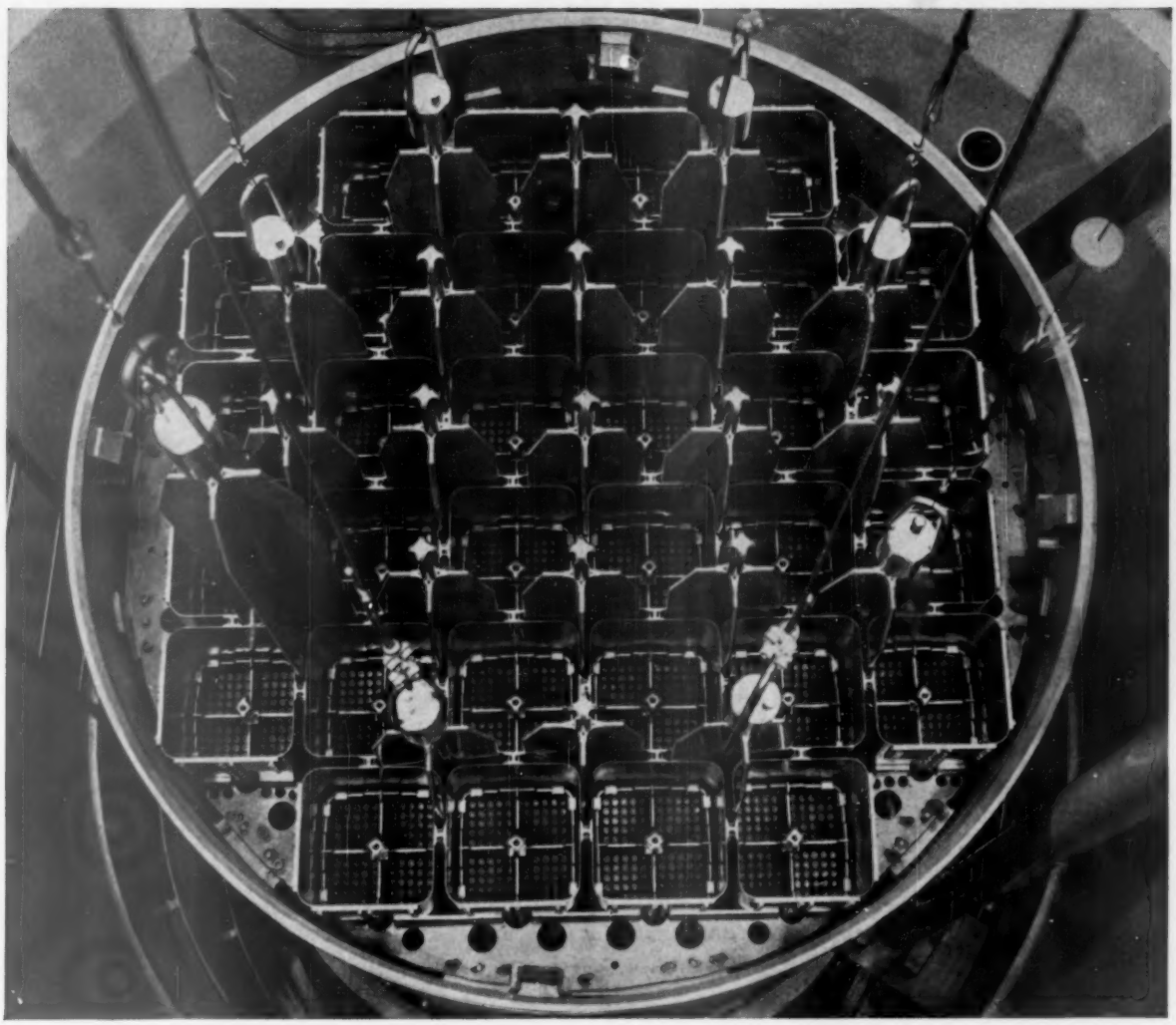
N.S. SAVANNAH PROGRESS REPORT:

CORE DESIGN CALCULATIONS CONFIRMED BY TEST AT CRITICALITY IN B&W LABORATORY



The core for the N. S. SAVANNAH was, for the first time, made critical (at zero power) in an open test tank at B&W's Critical Experiment Laboratory at Lynchburg, Virginia. Except for pressure and temperature, conditions of loading and start-up as nearly as possible duplicated those in the reactor pressure vessel. Design and engineering calculations were confirmed within closer limits than had been predicted.

Since radioactivity during and after operation will preclude further close inspection, tests such as these permit flexibility and accuracy impossible in the operating environment. Successful completion of the tests on this core—designed and built by B&W—is another step toward the sailing of the SAVANNAH—and the nuclear future of our merchant marine service. The Babcock & Wilcox Company, 161 East 42nd St., New York 17, New York.

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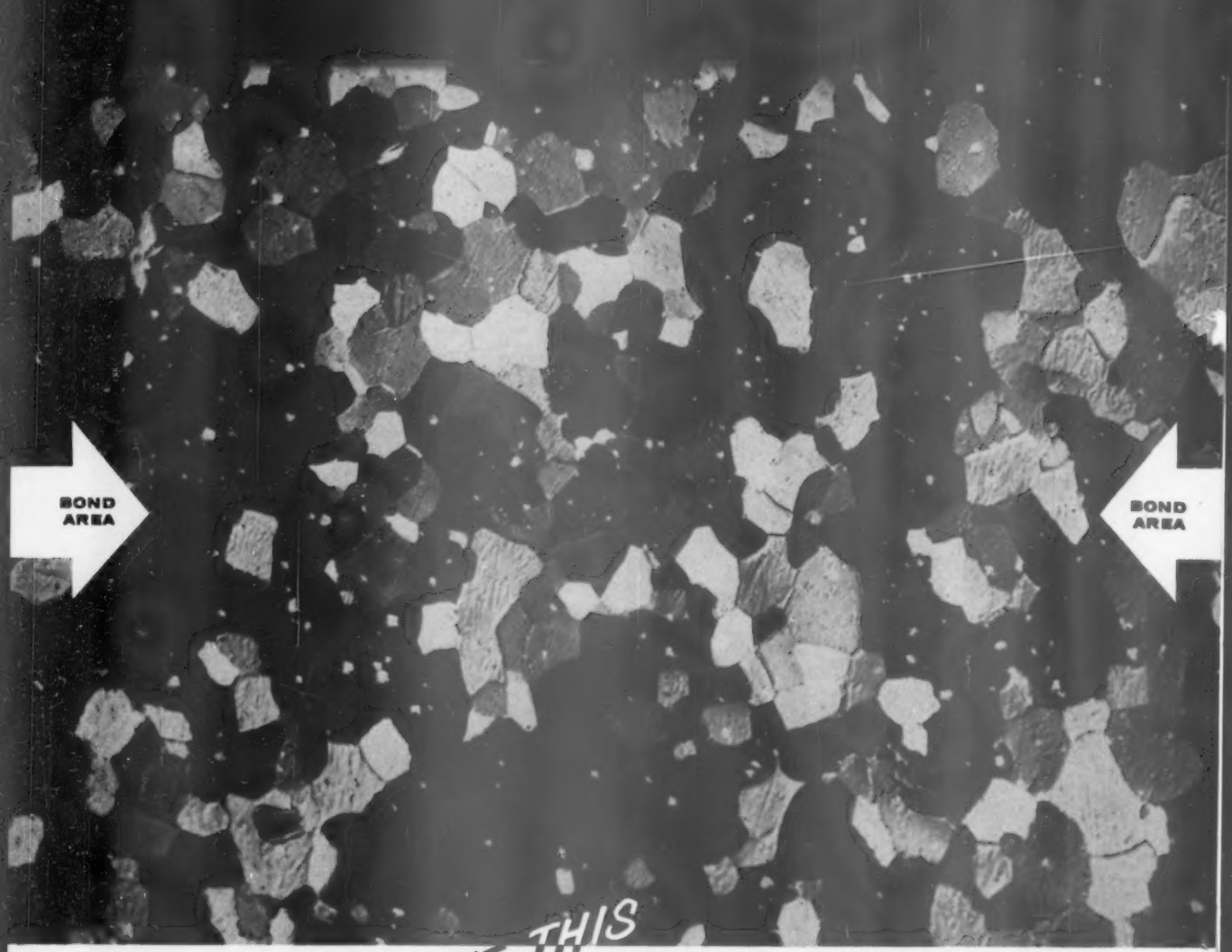

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NUCLEONICS

SEPTEMBER 1960

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

VOLUME 18 NUMBER 9

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- Magnetic Data Taping
- NASA Reactor Simulator

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...about NUCLEONICS

Sequel to a Best Seller

Significant interest in radiation effects goes back a long way—chemical effects of radiation have been studied from the early days of radioactivity research. The modern view, in particular the application of the effects of neutrons on the structure of matter, dates from Wigner's brilliant theoretical prediction of the damage neutrons would wreak in the graphite of the then-as-yet-unbuilt Hanford reactor. But large-scale engineering concern came only when radiation-effects data were revealed at the first Geneva conference.

To summarize the post-Geneva situation we carried back in September, 1956 (four years ago—my how time flies!) a major report under the title "How Radiation Affects Materials." That report proved to be one of the most useful we've ever published—reprint demand has exceeded it for no other technical report in the 13-year history of NUCLEONICS. Today there is a plethora of data—a whole information center has been set up at Battelle Memorial Institute to process it. Thus the need today is for interpretation of the data, for guide posts to the intelligent application of the data and for performance of further radiation-effects experiments. In addition there are some new themes—such as the effects of combined environments and the effect of pulses of radiation. These also need to be explored and interpreted. These things we have tried to do in the report on "Advances in Radiation Effects" that starts on page 63.

NEW STRENGTH. Judy Beach, new assistant editor, discusses article with Herb Taylor, new assistant art director

Meet Miss Beach

We told you last month that there was forthcoming an addition to the editorial staff in the area of our applied radiation and instrumentation coverage. It may surprise you (as it did some of us) that this addition should be a lady astronomer-editor. Yet Miss Beach, pictured below with assistant art director Herb Taylor (about whom we told you last month), is just that.

The first thing to learn about Margaret T. Beach is that, by some equation still unknown to nuclear physics, she is called Judy. She is a native New Yorker, a graduate of Smith College (B.A. *summa cum laude*), where her honors thesis as an astronomy major bore the imposing title of "A Study of the Distribution and Magnitudes of Galaxies Using the Palomar Observatory Sky Atlas with a Catalogue of 1033 New Bright and Faint Galaxies." She was a delegate in 1958 to the tenth general assembly of the International Astronomical Union in Moscow. In college, Judy was elected to Sigma Xi and Phi Beta Kappa. She comes to us from a science editor's job in the School Department of the McGraw-Hill Book Co.

—The Editors

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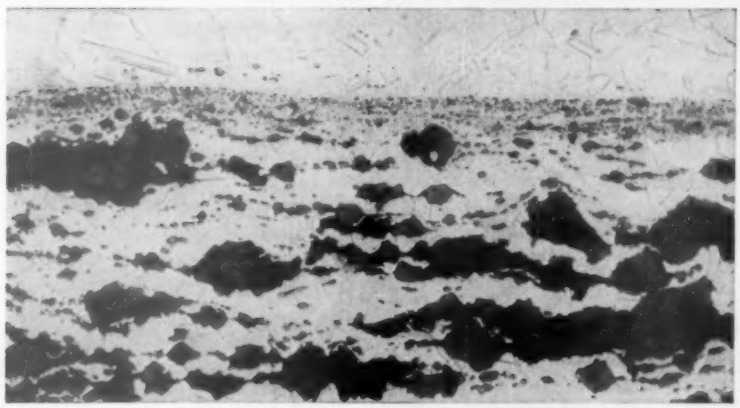
PM-1 zero power core, with control rods in place



Longitudinal clad-core interface, showing flame-sprayed zone

EFFECT OF TITANATE ADDITIVE ON HYDRATION CHARACTERISTICS
(Eu_2O_3 + 2 TiO_2)

Test	Weight % Change
160 hrs. in distilled H_2O	No change
150 hrs. in boiling H_2O	No change
140 hrs. in autoclave at 570°F at 1200 psi	0.04% loss

Europium oxide offers many advantages as a control rod material. In addition to its high cross section for thermal neutrons, it promises good epithermal absorption characteristics—an important factor in the compact, highly enriched core of the Martin PM–1,* where 35 percent of the neutrons are of epithermal energy. Europium generates no gases as a result of absorption. Its neutron absorption products add to its continuing control effectiveness.

Through the addition of various oxides, Martin metallurgists have overcome two basic problems associated with the use of europium—its tendencies to (1) hydrate and (2) react with silicon in the clad material.

Although SnO_2 and Fe_2O_3 were also tested as additives, the combination of TiO_2 and Eu_2O_3 provided greatest stability and proved to be the only material suitable for heat treatment in a reducing atmosphere. Various additions of titanium oxide to europium oxide, ranging from 1:1 to 1:2 mol ratio, produced stabilizing effects, with the higher additions of titanium showing greater stability.

While a simple mixture of europium oxide and iron powders was used in zero power tests, cermet cores of high ceramic content will be fabricated through normal hot rolling procedures for the PM-1. For the operational system, europium titanate represents 43 percent by weight in a matrix of pre-alloyed stainless steel—equivalent to 50 percent by volume. A flame spray coating on the surfaces of the core provides improved bonding.

Control blade coupons, utilizing the stabilized Eu_2O_3, have been defected to expose the meat and autoclaved for as long as 284 hours at 640°F and 2000 psi with no swelling, deformation or appreciable weight change.

*Packaged power plant being built under contract to the U.S. Atomic Energy Commission for installation at the Sundance, Wyoming, Air Force Station

At 00h00m01s GMT, September 1, 1960 Martin logged its 658,008,000th mile of space flight

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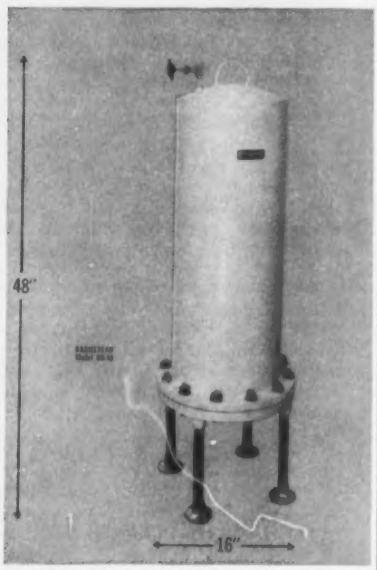

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NUCLEAR REACTIONS

Analogs for Transients

DEAR SIR:

At the end of the review, "The Engineering Design of Power Reactors" in the June NUCLEONICS, it is stated (p. 116) in the discussion of computer application to transient studies that analog computers are not satisfactory for evaluating accidental transients in detail.

Some readers are likely to be misled since the analysis of such transients on analog computers in any detail has been the subject of very few publications. Such studies have been carried out in Europe by the majority of builders of gas-cooled and other types of power reactors. These studies go far beyond considering the reactor as a point source of heat. Simultaneous heat-flow and neutron-diffusion equations are solved for a number of sections. This kind of work usually requires about 200 amplifiers and a large nonlinear complement. Almost every nuclear research group in Europe has or is planning an installation of this size for such purposes. One British company is completing construction of its own 1,500-amplifier analog computer for nuclear problems.

The limitations in absolute accuracy of the analog computer are usually quite consistent with the approximations implied by the mathematical model and engineering data. Even when the increase in time per run due to the use of a digital code can be accepted, one should consider the remark in C. E. Langlois' letter in the same issue (p. 6): "the indiscriminate use of high-speed computers causes the user to lose the 'feel' for his problem and thereby lessens his ability to properly interpret results and decide on proper courses of action." While this is true of all kinds of computers, it is quite generally recognized that analog work maintains a very close touch with the physical problems at all times.

—HANS WITSENHAUSEN,
Senior Consultant
European Computation Center (Brussels)
Princeton Computation Center
Electronic Associates, Inc.
Princeton, New Jersey

DEAR SIR:

Mr. Witsenhausen has a point in that the exact meaning of the discussion in the NUCLEONICS article could be misconstrued.

It was not the intention to imply that the accuracy of the numbers obtained from the analog is insufficient for detailed transient evaluation but rather that the accuracy of representation of the system wherein all the appropriate parameters could be included is insufficient with the usual analog systems. Because of the ability to get a "feel" for a problem with an analog computer, most organizations invest in a modest, general-purpose analog system containing usually less than 100 and, more often, less than 50 amplifiers. It is a system such as this that is not satisfactory for detailed evaluation of accidental transients.

It is recognized that an analog computer can be made to solve any transient problem to almost any degree of detail desired providing one is willing to invest in the amount of equipment necessary. Because of the investment involved, such machines are purchased only when sufficient demand exists, which means that the machine must be capable of serving a wide variety of problems.

Achieving flexibility with the analog machines that are generally available requires time-consuming rewiring and debugging for each problem. As the number of amplifiers increases, the practicability of using analogs in this manner diminishes. With a digital computer, one has greater flexibility. Once a program is set up, a run can be made as soon as the machine is available without the need for extensive set-up time.

—NUNZIO J. PALLADINO,
Professor and Head
Nuclear Engineering Department
The Pennsylvania State University
University Park, Pennsylvania

Corrections

DEAR SIR:

I would like to call your attention to an error in my article "Designing High-Pressure In-Pile Test Thimbles" (NU, May, 1960).

On p. 118, the equation for thermal stress, as submitted in my original manuscript, gives values double the correct amount plotted in Fig. 3. The equation should read

$$\frac{EHad^2}{16k(1-\mu)}\left(\frac{2\beta^2\ln\beta}{\beta^2-1}-\frac{3\beta^2-1}{2\beta^2}\right)$$

—MAX A. VOGEL
Experiment Engineering
Testing Reactor
Westinghouse Electric Corp.
Pittsburgh, Pennsylvania

DEAR SIR:

Several errors in the article, "Calibration of ORNL Lid-Tank Fission Plates" (NUCLEONICS, April, 1960, p. 98), by D. R. Otis and myself, were brought to our attention. In the table on p. 100, under the subheading "Estimate by Neutron Absorption Rate," the quantities V, G, F and P should be changed to 0.826, 0.919, 0.575 and $1.79 \times 10^{11} \pm 11\%$, respectively. These corrections change the final estimated power of SP-2 from $1.62 \times 10^{11} \pm 5\%$ fissions/sec to $1.66 \times 10^{11} \pm 5\%$.

—WHITTIE J. MCCOOL
Nuclear Power Engineering Department
Alco Products, Inc.
Schenectady, New York

DEAR SIR:

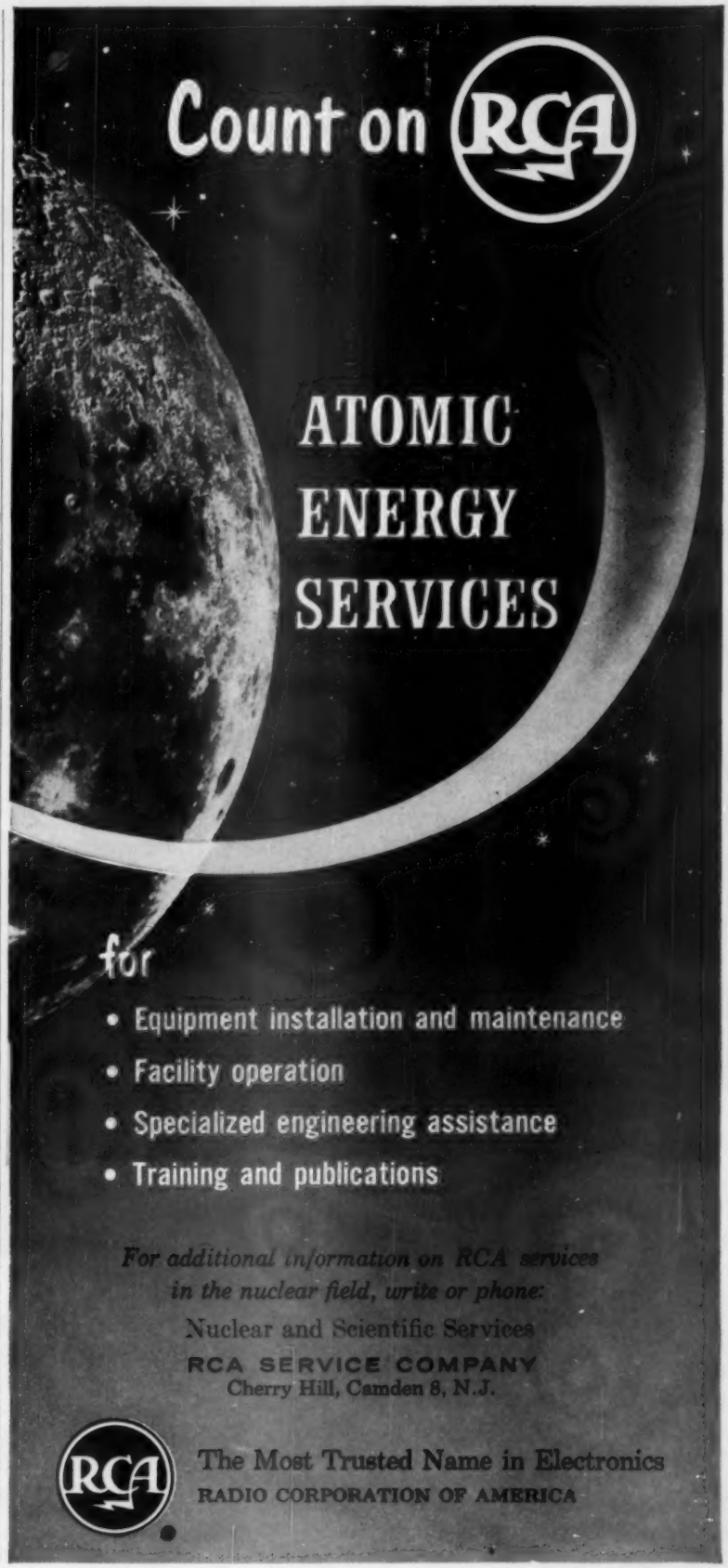
In my article "Hydrogen as Power Reactor Coolant" (NU, July, 1960, p. 84), several errors were made in the printing of the table entitled "Properties of Coolant Gases":

1. *All* properties are at 500° C and 10 atm—the title should have been asterisked and not the density column.
2. The chemical symbol for argon is A, not Ar.*
3. The values in the density column for H_2 and He should be 3.2 and 6.3, respectively, not 32 and 63.
4. All viscosity figures should be multiplied by 10^{-3}, i.e., 1.7×10^{-3}, 3.8×10^{-2}, etc.
5. Thermal conductivity units are 10^{-4} cals/cm/sec/°C, not 10^{-4} kcals/cm/sec/°C.
6. The thermal conductivity of argon should be 0.86 in these units, not 8.6.

This table, as you may remember, was sent at your request a few days before printing. I therefore had no opportunity to pick up any mistakes before this.

—D. BRADLEY
Chemical Engineering Division
Atomic Energy Research Establishment
Harwell, Didcot, Berks., England

* EDITOR'S NOTE: The new international standard abbreviation for argon is Ar.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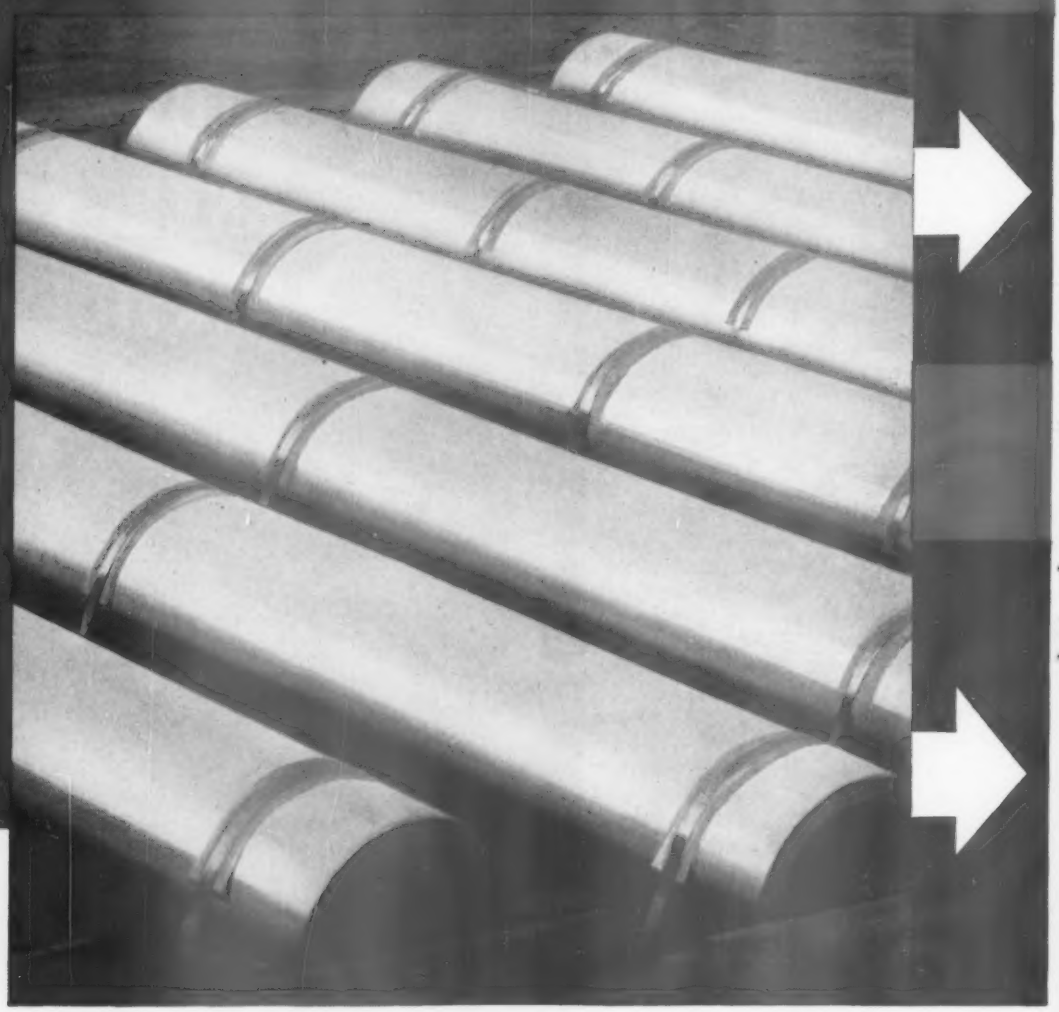

Centrifugal stainless steel castings readied for shipment by U.S. Pipe

The Government's new SPERT III nuclear plant at the National Reactor Station near Idaho Falls, Idaho, operating since December, 1958 to study nuclear reactor safety, uses U.S. Pipe's centrifugally cast stainless steel pipe for its coolant system.

SPERT III is classified as a high pressure, high temperature, light water moderated and cooled reactor. Its versatility permits transient tests under various initial conditions of pressure, temperature, and coolant flow. For example, pressures ranging from atmospheric to 2,500 psi and water temperatures from 68° to 668° F.

Another new nuclear power plant, engineered and constructed by Stone & Webster for Yankee Atomic Electric Company, is using centrifugally cast stainless steel heat exchanger shells made by U.S. Pipe and fabricated by the Southwestern Engineering Company in Los Angeles, Calif.

Stainless steel, centrifugally cast, made to rigid specifications, may be the answer to your piping or heat exchanger problem. For more information, write or call:

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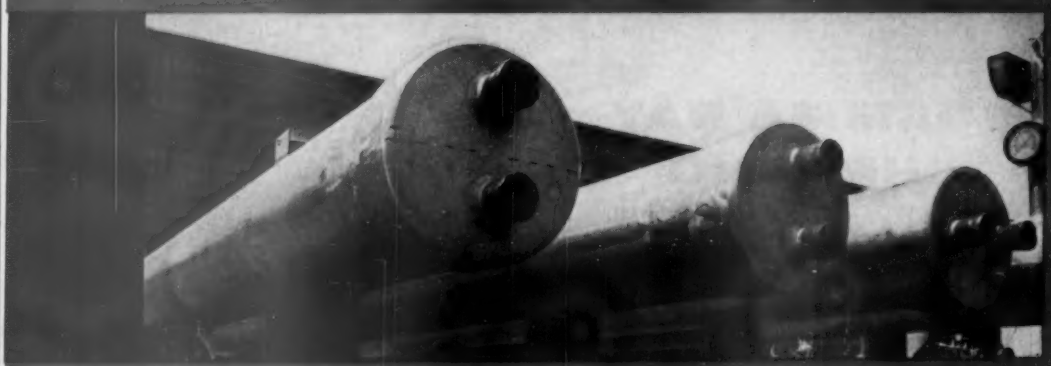
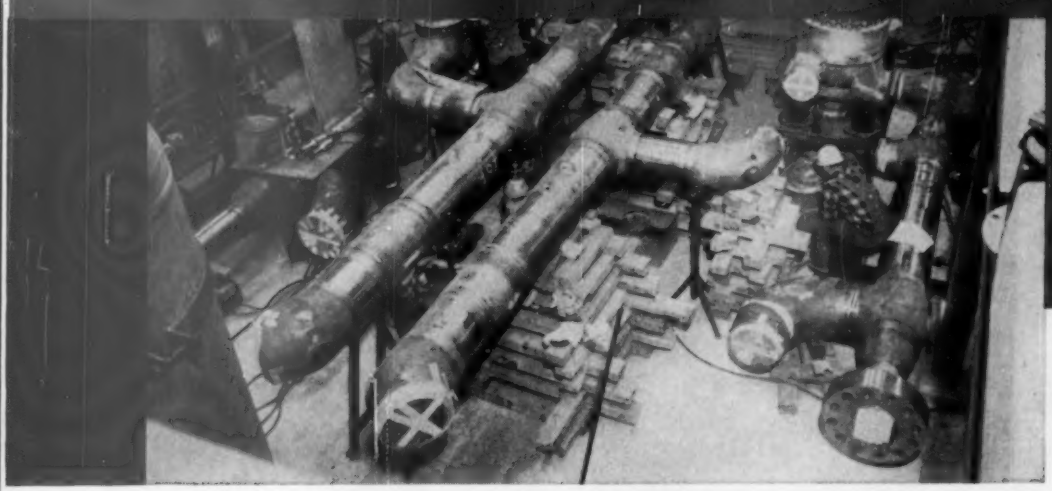
REQUIREMENTS OF NUCLEAR AND COOLANT SYSTEMS



Shop-fabricated heat exchanger shells of centrifugally cast stainless steel ready for shipment to the Yankee Atomic Electric plant at Rowe, Mass.

Subassemblies of primary coolant piping of centrifugally cast stainless steel being installed in SPERT III.



ASA PRESSURE PIPING CODE STATUS

Approval has been granted under this code for the use of centrifugally cast austenitic pipe for nuclear piping by Nuclear Case N-9. This case appeared in the April, 1960 issue of MECHANICAL ENGINEERING. Reprints on request.

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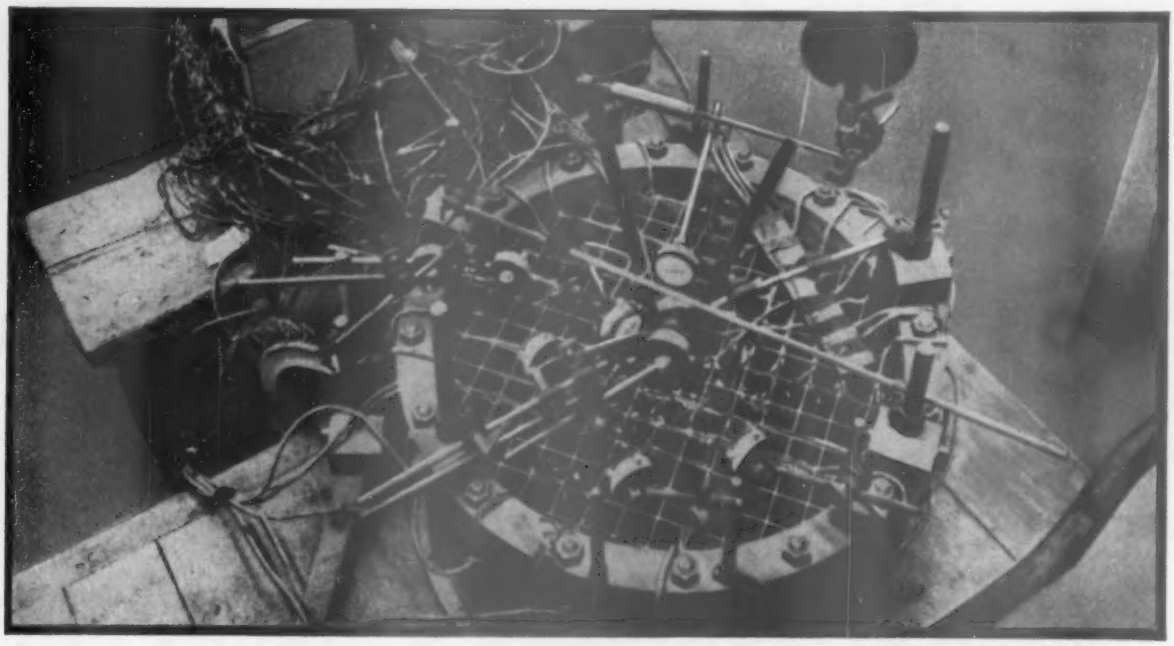

Strain Gages shown on ¼ Scale Model of PWR Top Grid

BETTIS ATOMIC POWER LABORATORY

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MINDS, METHODS & MACHINES

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- Precision metal removal equipment
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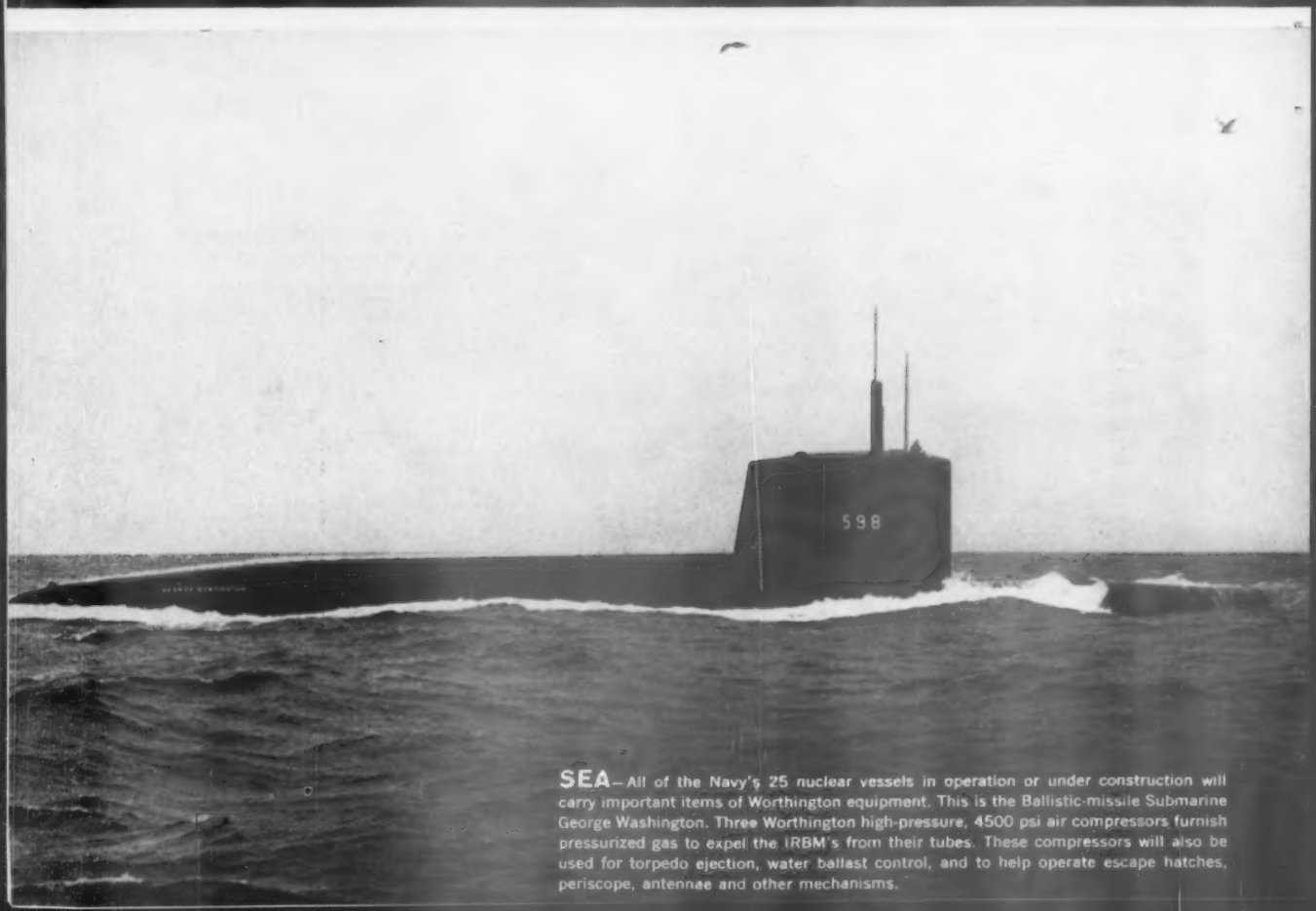
LAND— Every major nuclear power station under construction in the United States will use Worthington equipment. Above, a Worthington engineer discusses the installation of a 120,000 sq. ft. condenser in the Dresden Nuclear Power Station in Morris, Illinois. Worthington successfully solved many unusual problems in the design of this condenser including the necessity of handling full output of dump steam.



SEA— All of the Navy's 25 nuclear vessels in operation or under construction will carry important items of Worthington equipment. This is the Ballistic-missile Submarine George Washington. Three Worthington high-pressure, 4500 psi air compressors furnish pressurized gas to expel the IRBM's from their tubes. These compressors will also be used for torpedo ejection, water ballast control, and to help operate escape hatches, periscope, antennae and other mechanisms.

AIR—Portable Nuclear Power Plants which can be flown to remote locations are a reality because of such technical achievements as Worthington's aluminum tube condenser. Built for Alco Products, it will be a vital part of a nuclear plant installed in a tunnel located beneath the Arctic snow. The unit is 75% lighter than conventional condensers. It meets a 15-ton weight limitation for Air Force transportation.

LAND, SEA OR AIR

Worthington serves the nuclear industry

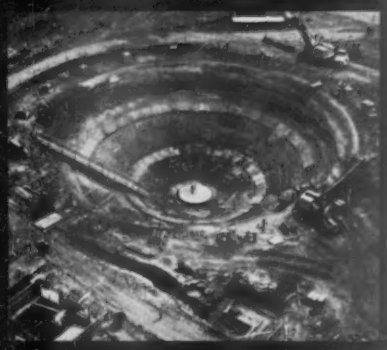
You can benefit from Worthington's experience in the nuclear field. Whether you are concerned with central station power plants, Navy and commercial ships, or packaged power plants, Worthington can help develop much of the primary and secondary cycle equipment you will need.

Worthington solved many special problems in the design of *condensers* for both the Enrico Fermi and Dresden Nuclear Power Plants. Special *high-pressure air compressors* were built by Worthington for installation in ballistic-missile nuclear submarines. Worthington also made significant design contributions to the *canned rotor pump* for circulating primary collant in reactor systems. The N.S. Savannah will go to sea with Worthington *buffer seal charging pumps*, a noteworthy application and design. A Worthington *turbine generator* is being used in the Argonne Low Power Reactor, a prototype nuclear packaged power plant for use in remote areas.

Your inquiries are invited. Please write to R. H. Davis, Manager, Marine and Nuclear Dept., Section 106-5, Harrison, New Jersey.

OFFICIAL U.S. NAVY PHOTO

WORTHINGTON



1. Plant construction begins with sphere excavation

2. Core computations checked in critical assembly

3. Vallecitos BWR furnishes vital operating data

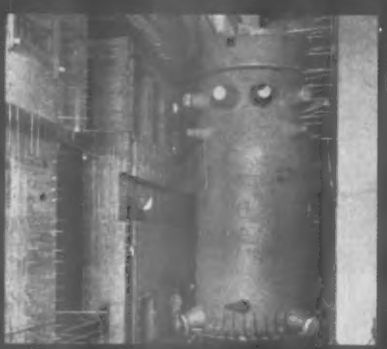
4. Reactor materials and fuel are evaluated

5. 190-ft diameter containment sphere takes shape

6. Refueling methods are studied by G-E engineers

7. 300-ton reactor pressure vessel arrives at site

8. Primary steam drum is readied for shipment



9. Reactor pressure vessel is placed in position

Dresden at full power

World's largest nuclear power reactor is providing first BWR plant operating data

On June 29, the Dresden Nuclear Power Station produced rated electrical output of 180,000 kilowatts net—three times the power produced by the next largest operating nuclear plant in the United States. The practical operability of large boiling water reactors has now been demonstrated, and the first actual operating data from a large-scale commercial nuclear plant is available to the designers of tomorrow's reactors.

Following a brief demonstration run at full power, the plant is undergoing a series of tests at various power levels. Operating results so far have confirmed General Electric's belief that large boiling water reactors are the most promising type to supply early economical power.

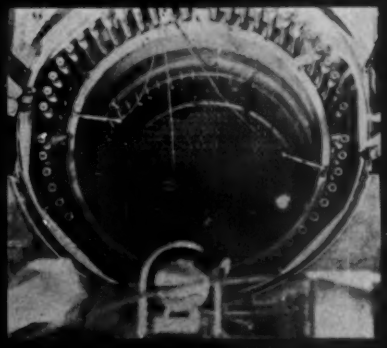
The pioneering Dresden station was designed and built by General Electric for the Commonwealth Edison Company and the Nuclear Power Group, Inc.*—with

General Electric
Boiling Water Reactor Technology
Helps Lower Nuclear Power Costs

VALLECITOS
BOILING WATER
REACTOR

10. Oxide fuel is manufactured by G.E. in San Jose

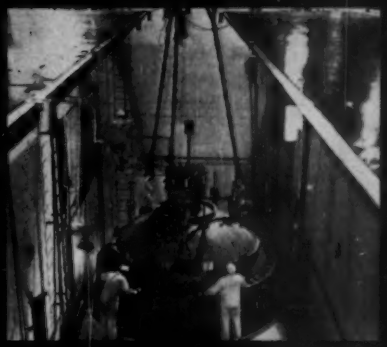
11. Rod-type fuel elements are assembled



12. Core contains over 60 tons of uranium fuel

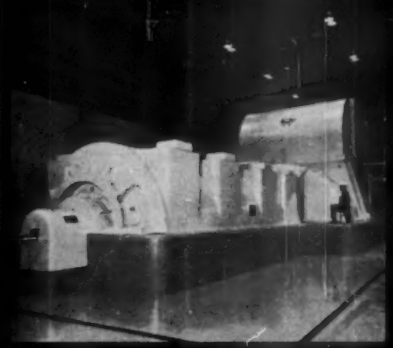
13. Modern instrumentation system is tested at site

14. Huge turning vane is installed in reactor



15. 56 bolts hold the pressure vessel head in place

16. Plant is operated from the main control room



17. Turbine-generator produces at 192,000-kw rate

18. Dresden – largest operating nuclear power plant

Bechtel Corporation as engineer-constructor. The plant is scheduled to be turned over to Commonwealth Edison Company this fall as a dependable power-producer on the Commonwealth Edison system.

For more information on General Electric's commercial nuclear activities, call your G-E Apparatus Sales Office, or write General Electric Company, Schenectady, New York. Outside the U.S. and Canada, write to International General Electric Company, 150 East 42nd Street, New York 17, N. Y. 132-06

* American Electric Power Service Corp.; Bechtel Corp.; Central Illinois Light Co.; Commonwealth Edison Co.; Illinois Power Co.; Kansas City Power & Light Co.; Pacific Gas & Electric Co.; Union Electric Co.

DRESDEN OPERATING RESULTS SO FAR

1. Core stability extremely high
2. Automatic load-following exceptionally good
3. Flat flux pattern throughout core as predicted.
4. Off-gas release negligible
5. Radiation levels in turbine area within permissible limits
6. Instrumentation remarkably trouble-free

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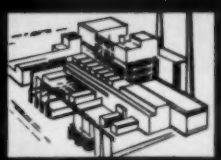
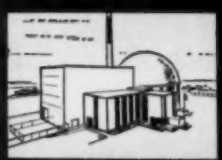
GENERAL ELECTRIC

DRESDEN NUCLEAR POWER STATION

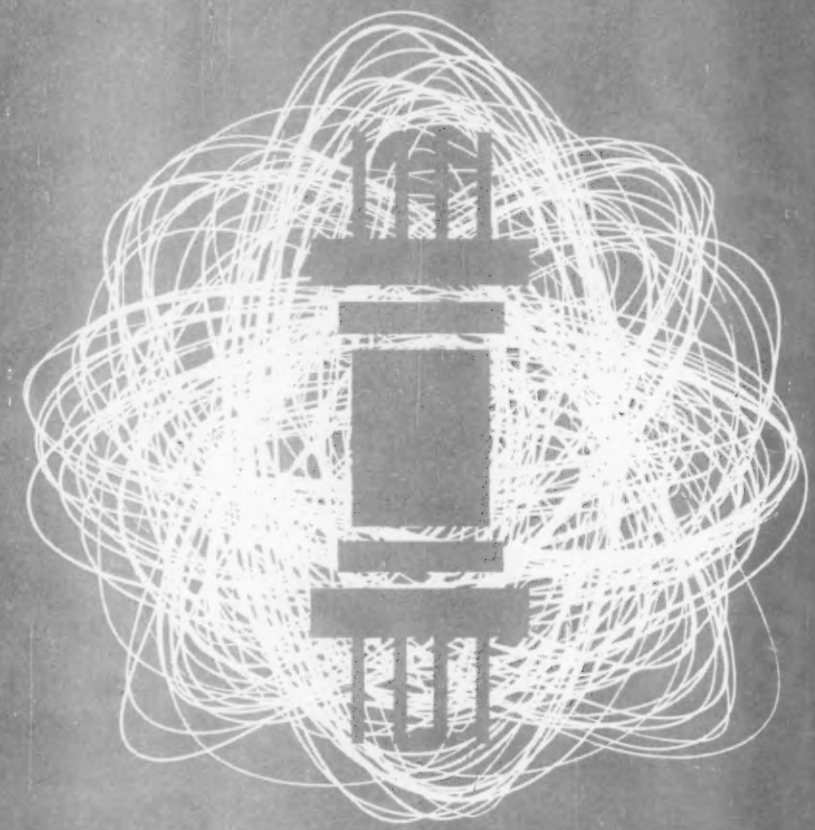


HUMBOLDT BAY NUCLEAR POWER STATION



BIG ROCK POINT POWER PLANT

MCR*



*Military Compact Reactor, a mobile, lightweight plant of 2,000 to 3,000 ekw, is being designed and developed by Nuclear Development Corporation of America (NDA) and General Motors as part of the U.S.A.E.C.—U.S. Army program to develop nuclear power for military use. Successful development would represent a significant advance in reactor technology and could be capable of fulfilling a variety of important military applications.

We would welcome the opportunity of discussing significant career positions with qualified *reactor* and *shielding physicists, programmers* and *nuclear engineers.*

Contact David Keller, Director of Personnel

NDA NUCLEAR DEVELOPMENT CORPORATION OF AMERICA

WHITE PLAINS, N. Y. TEL. WH 8-5800 / NDA EUROPE 31, RUE DU MARAIS, BRUSSELS, BELGIUM

Advances in Gas-centrifuge Enrichment Bring Big Problems

Late in World War II, as the Manhattan District scurried to develop enriched-uranium production facilities for the world's first nuclear weapons, the decision was made to go all-out on gaseous-diffusion separation of U-235 and to discard three alternative possibilities—electromagnetic, thermal diffusion and gas-centrifuge separation. More than 15 years later this decision—though it can hardly be challenged, even with the benefit of hindsight—has come back to haunt the Manhattan District's successor, AEC, and to present the Commission with one of the most delicate and difficult problems it has ever faced.

The problem is this: what to do about the re-emergence of gas ultracentrifuging as a promising means of enriching uranium? While the U. S. was virtually ignoring this technology, the West Germans and others have exploited high-tensile-strength materials not available 15 years ago to develop small, high-speed centrifuges which offer the real possibility—though not as yet the assurance—of producing fissionable material at reasonable cost. Two important related possibilities are these: 1. that these commercially developed machines may be able to produce enriched-U economically (thus competing with AEC's massive gaseous-diffusion complex); and 2. that this enrichment capability may spread to West Germany and others who do not now have it.

Both of these possibilities harbor headaches for AEC. Should gas technology be classified in the U. S. more or less after the fact, to inhibit its spread to non-weapons countries? How can the U. S. persuade, or cooperate with, West German and other nations with gas-centrifuge capability to prevent the spread of this technology? Should U. S. firms be permitted to buy, build and operate commercial enrichment plants (two firms —Thor-Westcliffe Research, Inc., of New Mexico and Decker Corp. of Philadelphia—have indicated such a desire and several others have expressed interest privately to AEC)? If so, what is to be done about the language in the 1954 Atomic Energy Act which requires AEC to hold title to all fissionable material? Would AEC be required to purchase all commercially produced enriched-U? Does AEC have an obligation to protect the government's $3-billion investment in gaseous-diffusion plants against the competition of cheaper fissionable material?

To Be Taken Seriously?

The basic question, of course, is this: Should gas centrifuging be taken seriously? The U. S. government's own answer is clearly "yes," as indicated by the tightening of secrecy on all gas-centrifuge technology (NU Wk, 4 Aug. '60, 1). With this secrecy ban in effect, according to AEC officials, hurried negotiations are under way to work out an international control system. AEC officials say the interest in gas-centrifuging on the part of U. S. firms is widespread, going well beyond the publicly declared interest of Thor-Westcliffe and Decker Corp.; others known to be interested include General Electric, Mallinckrodt Chemical and Sharpless Corp., Philadelphia.

As for the commercial importance of gas ultracentrifuging, AEC is officially pessimistic. There is no dearth of optimism, however, in both the U. S. and West Germany, where the lead in centrifuge development has been taken by Degussa and Wilhelm Groth. The latter has given exclusive rights to his process on the North American continent to Thor-Westcliffe (NU, Oct. '59, 17), although Thor-Westcliffe's plans to get seven developmental machines into operation this year have not jelled.

The nearest thing to an economic appraisal of gas centrifuging is a report written earlier this year for AEC. The author was Gernot Zippe, West German scientist who was awarded a German patent on gas centrifuges in June, along with Rudolf Scheffel and Max Steenback (*next page*). Zippe, who is the key man in the Degussa centrifuge program, was in this country when the patent was issued, working under a contract with AEC (via the Univ. of Virginia) to reproduce a short-bowl centrifuge he built for the Russians while an internee there six years ago. Zippe returned to Europe in July when his contract expired but not before rejecting "many offers" from U. S. firms.

Zippe Report

Zippe's report to AEC earlier this year is entitled, "Potential of the Short Bowl Gas Centrifuge for the Enrichment of the U-235 Isotope as Compared with Published Figures for Gas Diffusion (TID 5753)." Using estimates of General Electric's Karl Cohen (NU, Jan. '58, 66), Zippe said

4 associations explore joint federal-competition effort

Possible cooperation on the fight over government over competition with industry—particularly in the nuclear field—was explored last month by representatives of Edison Electric Institute, Manufacturing Chemists Assn., National Assn. of Manufacturers and U. S. Chamber of Commerce. Organization of a four-association committee was put off until each of the attendees could get the reaction of their respective associations. The group would not attempt to speak for any of the associations, rather it would be advisory and attempt to channel specific anti-competition activity to the association best fitted to handle it.

Meanwhile, the Chamber of Commerce has formed a task force to work for a better public attitude toward atomic energy.

Florida reactor postponed 1–2 years

The Florida West Coast reactor's research-development program has been "reoriented" to focus on technical problems of using beryllium as cladding material instead of stainless steel. This, AEC said, "is expected to delay completion of the plant, originally scheduled for July 1963, by from one to two years"—as forecast (NU, July '60, 28).

AEC was spending about $634-million/yr to produce 77,777 kg/yr of U enriched to 90%. Again based on Cohen's power-consumption estimates, Zippe said 2,940 kwh electricity were consumed to separate one kilogram U; on these bases, AEC's investment in this kilogram was $135, he estimated.

For the cost comparison, Zippe used his "small model" centrifuge (dubbed the "Virginia" centrifuge), with length of 30.5 cm (12 in.) and peripheral speed of 350 meters/sec; Zippe said the experimental efficiency of this machine was less than one-third that shown to be possible in the literature by both Groth and Prof. Jesse W. Beams, head of AEC's classified program at the Univ. of Virginia. Zippe said the small machine would separate 0.3 kg U/yr, using 260 kwh/kg; power consumption of the spinning rotor was experimentally determined as 8.9 watts, with a "quite poor" driving-motor efficiency of ~25%. Taking motor improvements and other factors into consideration, Zippe estimated that power consumption would be "roughly 10% of that of gas diffusion . . . for the same amount of separative work.

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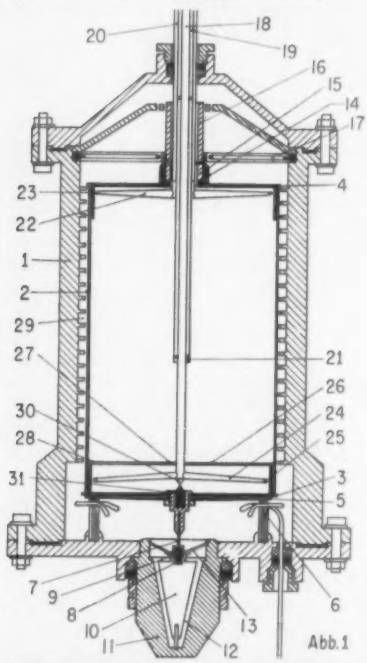


Abb.1

COMPONENTS OF DEGUSSA CENTRIFUGE on which German patent was issued in June: 1. housing; 2. rotor; 3, 4. covers; 5. steel anchor-shaped ring outside cover, with 6. spur-geared stator opposite ring; 7. flexible shaft, which runs on 8. hard plate and is surrounded by 9. guiding sleeve; 10. damping element resting in 11. oil bath inside 12. bearing socket; 13. spring maintaining rotor position; 14. collarlike appurtenance in which 15. hollow iron cylinder is partly inserted; above cylinder is 16. magnet connected to housing through 17. damping elements; 18. gas outflow pipe; 19. gas entry pipe; 20. evacuation pipe running off transverse pipes; 21. end of gas entry pipe (19); 22. transverse pipes rotate opposite rotor with 23. openings near rotor wall; 24. lower pipes also have 25. intakes for gas; 26. rigid dividing wall with 27. central and 28. peripheral openings; 29. continuous depression in housing wall (a winding groove); 30. iron core holding pipe system in position and 31. corresponding permanent magnet

"The main power consumption of the gas diffusion method is caused by pumping tremendous amounts of uranium hexafluoride and cannot be improved. On the other hand, sufficient pressure head for feeding the separated fractions from one [gas centrifuge] stage to the next, without external pumping, is already included in the 8.9-watt figure for the centrifuge. In addition, the way to further improvement is open."

Cost of manufacturing the "Virginia" centrifuge in the U. S. was estimated by Zippe at $1,000/unit in small lots of 10–50. Dividing this by 0.3 kg/yr, estimated cost of separation was $3333/kg.

"This figure," Zippe commented, "is about 25 times higher than the corresponding value for the gas diffusion method, although the cost per unit might come down by as much as a factor of two if one tooled up to produce large quantities of the machine. The above estimate also does not include costs of regulating devices and collecting arrangements for a cascade. The nature of such devices is as yet unknown.

"There is no question these investment costs are unbearable."

Later Models

Running through Zippe's comparison— but not stated—is a critical point: that is, that the "Virginia" machine is several years old and has been rendered obsolete by subsequent development work. To reflect the more current picture, he compared Cohen's gaseous-diffusion figures with a Degussa machine of later vintage. This machine would cost $235/unit in small lots, he said, with length of 46.5 (18 in.) and peripheral speed of 400 meters/sec.

Extrapolating the cost data "to this small Degussa model (a larger one is under development)," Zippe continued, "according to the theory that says that the separative work increases according to the 4th power of the peripheral velocity and the first power of effective length, one finds an increase of separative work [to 0.781 kg/yr]." Cost of separating this material, he estimated, would be $301/kg/yr, as compared with $135 kg/yr for gaseous diffusion.

"The uncertainty in this calculation," Zippe noted, "is the cost of the auxiliary equipment in a cascade arrangement necessary to obtain the desired enrichment factor. Experience with the present machines at Virginia has shown that one would expect the specific power consumption to decrease with increasing speed and to vary little with the size of the machine."

"One can conclude," he asserted, "that it is important to pursue the gas-centrifuge method itself and, especially, experiments to increase the efficiency of the separative work in the single stage units. Furthermore, work should be done as soon as possible on the development of regulating and gas-handling devices of the cascade arrangement, as well as on the development of larger rotors with high peripheral speed.

"It appears as though with this basic mechanical design, one gains more rapidly in separative work than the power requirement and investment costs increase—as one goes to higher speeds."

Zippe, just before he returned home, suggested that the U. S. increase its research-development in this technology, concentrating on bearing development and cascading. Such a program should run at least three years, he said, at a cost of about $1-million/yr. "If one would go to a larger [Degussa is developing a one-meter machine] and faster model [faster than 400 meters/sec] there is a great chance that, if one puts the necessary money in, the machine would very well compete with gas diffusion," Zippe contended.

AEC, Fuel Industry in Fruitless Go-round on NPR Fuel Billets

AEC and major elements of the nuclear fuels industry reached the end of the road last month in an unsuccessful experiment on reducing AEC competition with industry. Before the month was out, the Commission sent unwelcome word to four bidders that their proposals to supply several million dollars' worth of fuel billets for the New Production Reactor were too high, that AEC would perform the work in its own facilities for reasons of economy.

The events leading up to AEC's decision constitute a remarkable case history—with bitter overtones for industry—on the complexity and difficulty of trying to break down government competition. It is a case history that is particularly revealing because: 1. there can be little doubt that the Commission considered itself sincere in giving industry an opportunity to take on this production job; 2. industry officials contacted by NUCLEONICS were unanimous in arguing that AEC had no sound reason for performing the work itself, regardless of comparative cost estimates; and 3. AEC, once again, found itself unable to justify the spending of the taxpayer dollars for work it felt could be done considerably cheaper in its facilities.

AEC's offer was this: to procure from industry, if reasonable prices were quoted, 800–900 tons of slightly enriched uranium billets for co-extrusion with zircaloy-2 at Hanford into NPR fuel elements. Delivery schedule called for ten billets each in October and November this year with a gradual build-up to a ceiling of 60 tons/month in 1961 and into the early months of 1962; much of the early requirement (1.6% enrichment) will be used in the fuel-element development program, but the bulk of the material (0.947% enrichment) will go into the production elements.

Why Was Industry Asked?

There are two versions of how AEC decided to give industry an opportunity to bid. Industry officials say AEC General Manager A. R. Luedecke attended a meeting of the nuclear committee of the Manufacturing Chemists Association last fall and was asked why AEC was scheduling the work in its own facilities; Luedecke raised this question with his staff and it was decided to invite MCA to sponsor a survey of industry's ability to handle the billets. The AEC version is that the Commission, when it was asked by the staff to approve a $1.8-million expenditure for equipment to produce the billets at Fernald, Ohio, asked whether industry could do the work. In any case, there was never serious doubt that Hanford would manufacture the elements themselves because of AEC's feeling that fuel-element development was an integral part of NPR development.

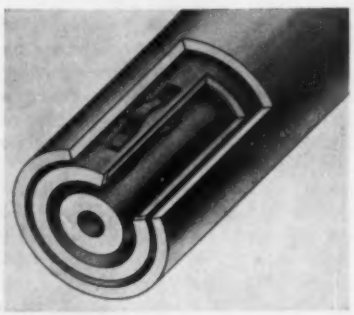
MCA organized a committee of its own members and representatives of fuel fabricators to study the AEC billet need and survey industry capability. The committee, headed by George Wunder of National Lead Co., reported back to Luedecke that industry could do the work and would like to bid on either a fixed-price or best-effort basis (wherein AEC would have to accept all billets, good and bad, as in its own facilities).

AEC's invitation for fixed-price proposals went out this spring, covering billet needs for the first core loading and extra elements. AEC could give no guarantee of subsequent billet procurement but the possibility—if not probability—existed that year-to-year purchases would be made from industry. AEC felt it could not take options for the post-first-core period because of legal bars to long-term contractual commitments.

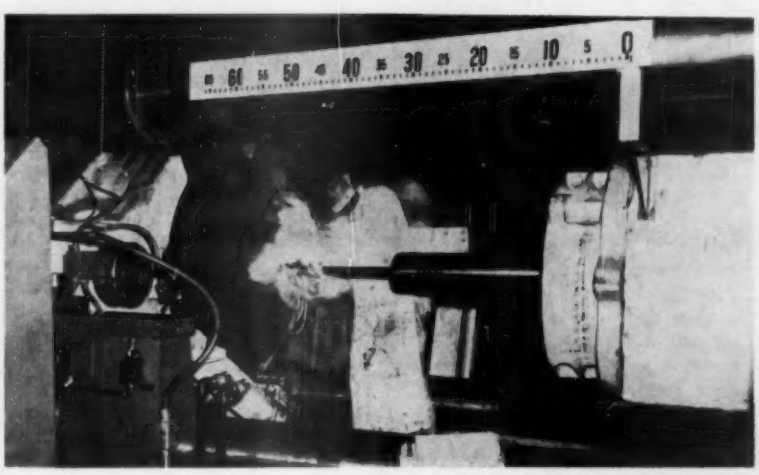
On July 5, four bids were received: Engelhard Industries, National Lead, Westinghouse and (jointly) Mallinckrodt Nuclear and Olin-Mathieson. Davison Chemical was subcontracting bidder to the first three on conversion of UF_4 to UF_6 to metal. Mallinckrodt was doing the same in its joint venture, with the fabricators converting the metal "derbies" to ingots, drilling these, hot extruding and rough machining. Hanford, with its huge co-extrusion press (*see photo*), will co-extrude the metal with its zircaloy-2 cladding for finishing as tube-in-tube fuel elements of 2–3 ft in length.

The Impasse

In view of AEC's bona fide desire to give industry a chance at this huge procurement, why did it choose self-manufacture? AEC officials have several answers: 1. the Commission must protect the taxpayer and cannot "subsidize" anyone in industry; 2. in "farming out" work, AEC can justify a higher industry price (than government cost) only when it gives industry capability which might lead to better and cheaper services for the nuclear industry (and, according to AEC officials, the ability to produce



ZIRCONIUM-CLAD FUEL ELEMENT for the New Production Reactor, shown in artist's drawing at right, is a tube-in-tube configuration (note spacers), with outer process tube of zirconium. The 0.947%-enriched metal elements will be coextruded, rather than canned



HANFORD'S 2,750-TON COEXTRUSION PRESS, below, will process uranium-metal billets produced at AEC's Fernald, Ohio, and Weldon Spring, Mo., feed-materials plants. Uranium-zirconium shapes turned out of the press will be finished into fuel elements by other equipment housed in the $3.6-million cladding facility built for NPR

U metal is not too meaningful in view of the trend toward oxide and other ceramic fuels); 3. AEC would be criticized by Congress if it accepted industry bids substantially higher than AEC's costs.

Industry's views could be summarized in one question: Does the government really mean it when it says it does not want to compete with industry, particularly for a non-development job? Some typical industry comments:

"If the contract had been long term, the situation would have been entirely different. Industry gave a fixed-price guarantee on quality and you have to put in some 'fat' to take care of that [faulty billets] because Hanford has the turn-down on faulty billets. Best-effort bids would have been substantially lower and I think the bids would come down substantially on volume. I think industry should get this work—we'll have to break this [competition] some time. But I would say we have been given a fair hearing."

"When there is a need AEC should let private industry manufacture the material. It's a matter of survival. They can have some justification in giving this business to private industry because it is helping us to reach economic nuclear power quicker."

"There is no question that industry can produce this material cheaper than AEC [over the long term] regardless what AEC says its costs are."

AEC officials said their cost estimates, which were prepared pursuant to Budget Bureau criteria for comparisons with industry prices, reflected operating costs, amortization, use charges (for the fuel material), losses likely to be incurred, interest, use of capital for the entire billet-making operation (including the $1.8-million for Fernald), insurance and third-party liability indemnity, taxes, and salaries and other administrative costs; no profit factor was included.

NPR Fuel Elements

The tube-in-tube elements (with a third, outer process tube of zirconium) under development for NPR will serve to meet the needs of both plutonium and electricity production, if NPR is eventually converted to a dual-purpose reactor; they would not be adequate if NPR were converted for power production only.

A thin cladding of zircaloy-2 has been decided upon to reflect the relatively short exposure period and the lower temperatures than are usual for power reactors. However, temperature, pressure and exposure conditions will be severe enough to have dictated zirconium over aluminum.

AEC, PRDC Ask Supreme Court to Review Permit Validity; Fermi Work Continues but Criticality Off to Mid-'61

Power Reactor Development Co. filed papers with the Supreme Court in mid-August requesting a writ of certiorari [review of the case] in the matter of the AEC construction permit for the Enrico Fermi fast breeder reactor at Lagoona Beach, Mich. AEC had already asked the Justice Department to take the necessary legal steps to seek Supreme Court review.

AEC's construction permit, granted Aug. 4, 1956, and under continuous fire since then by three labor unions, was invalidated in a 2–1 decision of the Circuit Court of Appeals June 10, 1960. An appeal by AEC and PRDC for review by the full nine-man Circuit Court bench was denied July 25.

One day later, on July 26, PRDC asked the Court for a stay of execution of the decision setting aside the construction permit. Granted Aug. 9, it permits PRDC to continue work on the reactor either until the Supreme Court denies review, or until—having agreed to review—the Supreme Court hands down a decision. PRDC feels the reactor is so close to completion that it is important that it be allowed to finish construction so that the non-nuclear testing program may proceed. Interruption of work now would only cost the project more money, a PRDC official told NUCLEONICS.

Work Proceeds at Site

Meanwhile back at Lagoona Beach, work is continuing on non-nuclear testing of the reactor systems. Just before the Court of Appeals threw down the construction permit, PRDC had been planning to take the reactor critical for the first time in March or April 1961, at conclusion of the non-nuclear test work. Now it is planned —if there is no resolution to the legal question by that time—to carry out additional experimental work as part of the non-nuclear testing program, in which molten sodium is circulated in the primary at operating temperature, heated by electrical heaters.

Two months of heavy construction work now remain before the final phases of the non-nuclear testing can be carried through to completion. Most of this is centered in the plant control room, where cable-pulling and hooking-up of controls has yet to be completed. A changeover will have to be made at the conclusion of the non-nuclear testing program from test equipment to the permanent plant controls. Also remaining to be done is site completion and cleanup. After that, only fuel loading and installation of control rods will remain to be done (the control rods are to be installed and tested prior to fuel loading in any case). The turbine-generator set should be completed within the next two months also.

Appeal to Supreme Court

In placing its case before the highest court in the land, PRDC declared, "A majority of the court below [the Circuit Court] has pre-empted the roles of Congress and the [Atomic Energy] Commission by writing into the law its particular ideas of what would be sound atomic energy policy. It has done so with respect to matters that were not only plainly entrusted to the Atomic Energy Commission's expert discretion by Congress, but that fall in an area which, above all others, requires the evaluation of complex technical information by those specially qualified to do this. If this decision stands it will impede rather than further the plainly declared Congressional purpose of encouraging the most rapid development of the peaceful application of nuclear energy which is consistent with adequate protection of the public health and safety.

"In holding the provisional construction permit order of the Commission to be now reviewable [by the courts] at the instance of these respondents [the unions], the court below has also rendered a decision inconsistent with basic principles of judicial review laid down by this Court and accepted in other circuits."

Supreme Court: Alternatives

If the Supreme Court will review the case and decides favorably to PRDC—a decision that could hardly come at the earliest much before next spring—PRDC will then apply for an operating license. Procedures required at that time involving the Advisory Committee on Reactor Safeguards and AEC's Hearing Examiner mean that at least two months must elapse before a low-power operating license can be issued. Thus it is unlikely that criticality will occur at Lagoona Beach before midsummer 1961.

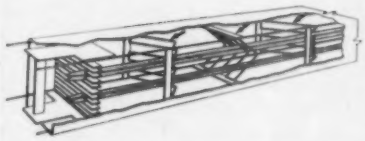
On the other hand, should the Supreme Court either deny review or decide in favor of the unions, PRDC's only remaining recourse would be to return to AEC for a review of the original construction permit; it might be necessary to return to Congress for review of applicable legislation.

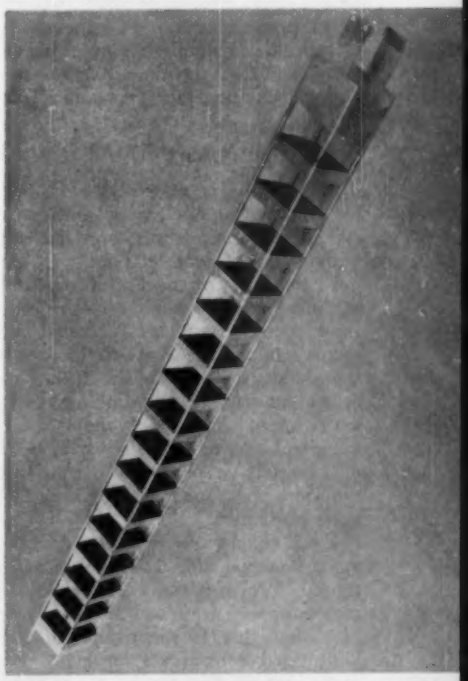
NEARING ITS FINAL APPEARANCE, the Fermi fast breeder externally seems to need only site cleanup and landscaping. Principal features include: 1. reactor containment building; 2. boiler house; 3. turbine-generator building; 4. control center; 5. plant offices; 6. fuel element and repair building; 7. health physics building; 8. sodium purification and storage; 9. inert gas building. Lake Erie is at top of photo, with a natural lagoon in foreground

Fermi Reactor Nearing Completion

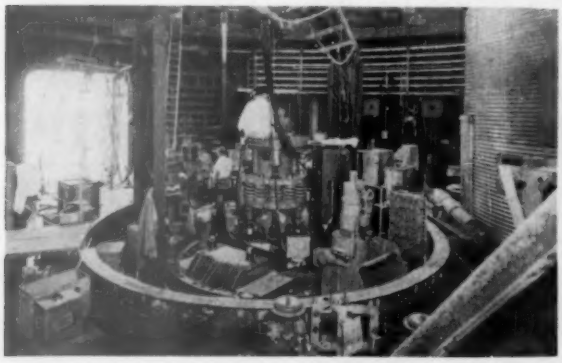
A force of about 400 (skilled and unskilled labor and supervisors) plus 20–30 technical personnel running the test program are now working at the Enrico Fermi Atomic Power Plant to complete construction. Work is continuing at the same rate as before the adverse court decision (*see opposite page*), neither accelerated nor slowed down; normally there is only one shift, although occasionally a second shift is called on to surmount humps.

The nonnuclear test program, 10–15% completed, is starting hot gas testing. Late last month the reactor temperature was being brought up to 500–525° F, after which the primary and intermediate loops were to be filled with sodium for the first time. The intermediate loop is just being completed. A lot of component acceptance testing has been running concurrently with equipment erection the last two months.

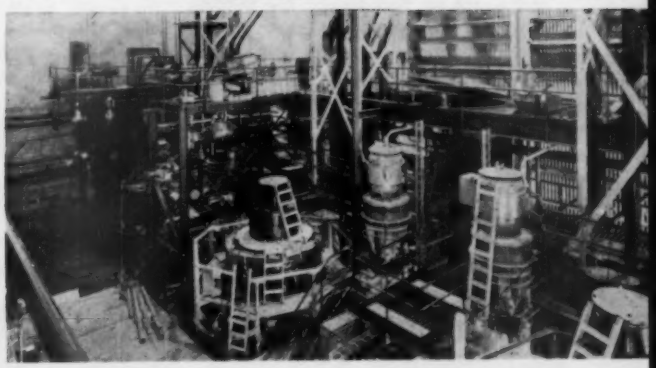




BEFORE AND AFTER: The discarded birdcage arrangement (above, arrows) which permitted the fuel rods to move in one plane where they were unsupported, resulting in corkscrew-like distortions in the rods and opening up the risk of hot-spots developing that might in turn lead to local melting. (Right) "Honeycomb Birdcage No. 8," adopted after extensive testing as an alternate support system that would utilize the same pins already in fabrication but hold them in a more rigid assembly. Orders for fabrication of the honeycomb grid were to be placed late last month



INSIDE REACTOR DOME: top of primary shield tank in foreground; man (center) is seated on hold-down mechanism; to either side, drive motors for rotating shield plug and offset handling mechanism



INSIDE BOILER HOUSE: prominent are two sodium pumps (right of center) and two main sodium-to-water heat exchangers (just left of center and, only top showing, bottom right corner)

Savannah Schedule Shows Slippage; Await ACRS Action

NS *Savannah* has lost some more time from her precritical startup schedule. At the beginning of the year, fuel loading was slated to take place in April or May; most recent schedule called for mid-August. But present estimates for start of fuel loading for the world's first nuclear merchant ship range from October to December, with the latter part of that trimester probably a better bet. Achievement of criticality may take several weeks more after insertion of the fuel elements.

The core itself has passed criticality testing in Babcock & Wilcox's critical facility at Lynchburg, Va., and is now there awaiting shipment.

Reason for the slippage is attributed by project officials to the extreme stringency—and time-consuming nature—of the tests prescribed for the ship's propulsion system. Philosophy of the joint AEC-Maritime Administration organization—the "customer" for *Savannah*—is that whereas in a conventional ship a lot of minor bugs are expected to appear and be ironed out on the trials, a nuclear ship—especially a first one—simply cannot afford to have any bugs at all at sea, not even on trials.

"I *know* there are no technical problems," a project official told NUCLEONICS; "it's just a straightforward testing of systems—and of getting AEC approval via the Advisory Committee on Reactor Safeguards."

Savannah is now in transition from the startup program's Phase I (static precritical systems testing) to Phase II (dynamic precritical testing). Phase III will include fuel loading, criticality, and low-power operation for physics testing; IV is dockside power testing, and V the seatrials.

Right now it is not yet clear whether *Savannah's* reactor will be brought to criticality and run at low power at the Camden, N. J. yards of N. Y. Shipbuilding Co., or not. ACRS has not yet ruled on the proposed startup plans. The yard would like to take the reactor to at least 18% of its 69-Mwth power at her fitting-out berth, but AEC has not yet approved this. Alternate test sites under consideration are Harbor of Refuge on the lower Delaware estuary, and Yorktown, Va. High- and full-power testing prior to sea trials will probably be done at Yorktown.

In preparing to consider *Savannah's* hazards report, ACRS is known to feel that caution is justified, the pioneer merchantman being unprecedented in that 1. most Navy A-ships had a well-checked-out prototype, unlike *Savannah;* 2. every Navy A-ship has a crew, as well as officers, thoroughly trained—again unlike *Savannah;* and 3. that the Camden-Philadelphia area is more thickly populated than the places where the submarine reactors were started up.

Ship Operators Still View Nuclear Power with Interest—but at Arm's Length

Ship operators' view of the outlook for commercial nuclear propulsion is still bleak for the short term but not without bright spots of hope.

In the wake of the Forum meeting in Philadelphia four months ago (NU, June '60, 25) NUCLEONICS carried out a small informal survey of the group that holds the key to the future of atomic merchant ships but has been least heard from: not the reactor manufacturers nor the shipyards, both of whom have products to sell, but the ship operators who are the ultimate customers.

First conclusion: without government financial aid, it will be a long time before any commercial nuclear merchant ship contracts are awarded. Not that this is surprising: in the land-based central station field, one can count on two fingers the utilities powerful enough to undertake a self-financed major reactor project by themselves as Con Edison and Pacific Gas & Electric have done. And pools for joint operation are not as feasible in the shipping as in the electric utility business. Additionally, the shipping industry is in a depression: "I've got ships coming out of my ears; 25% of all available ships are laid up," said one executive.

On the other side of the ledger: as long as ships consume some 255 barrels of fuel oil each day at sea—or a barrel every five minutes, at $2.39/bbl (New York harbor price)—ship operators are going to be making flirty eyes at any prime mover that holds out any promise of being cheaper.

Major surprise of the survey was a recent change of attitude by American President Lines, which has been hoping for some time to build—with government aid—a superliner for transpacific service. (The ship actually was authorized by Congress but funds were not appropriated.) APL testified before Congress in 1958 that although it had "devoted a great deal of thought and study and invested considerable sums in research and training" on nuclear power, it found that "immoderate financial risk" was involved in using it now (50% more than an equivalent ship in capital cost and $1.1-million/yr more in operating cost).

Last month, however, an APL official told NUCLEONICS that company policy had just changed; that for passenger ships on a long run, nuclear propulsion may now be economic much earlier than had originally been thought; and that APL would not now build any large passenger ship without making exhaustive studies to determine if the ship should be nuclear-propelled. APL agreed that the Forum paper at Philadelphia by David L. Gorman of Geo. G. Sharp Inc. had been an eye-opener ("on the Pacific run the [nuclear] express passenger liner appears to be fully competitive with the conventional ship at 31 knots, and very nearly so at 26 knots").

On the other hand the United States Lines, which two years ago—after a study—turned down nuclear propulsion for the proposed sistership to its transatlantic superliner *United States,* said it believed commercial nuclear power to be just as far away as two years ago. However USL said—as did every line surveyed—that it was watching nuclear developments very closely and keeping up with latest advances and thinking.

Tanker operators likewise were bearish, although Isbrandtsen—which had offered two years ago to build a gas-cooled reactor propelled tanker and to split the cost differential with the government (NU, March '59, 19), only to see the government fail to match its offer—said it might resubmit its offer if the new Administration and Congress were more favorably minded. "The whole thing turns on whether the government wants a nuclear merchant marine or not want one."

At present only one operator actually has a nuclear ship on its hands—although not yet at sea: States Marine Lines, which will operate *Savannah* for the account of the government. NUCLEONICS asked States Marine why, other than for prestige, it was spending its own as well as the government's money to take on the headaches and risks of this pioneering venture. Replied a high official of the line, "We want to be in on the inside, on the ground floor. We will be in a much better position to evaluate the numbers on nuclear propulsion having had the experience with *Savannah.* Anyone with our fuel bill, for keeping 80 ships at sea, has to look at any alternate fuel."

Zinn and Combustion Still Looking for a Major Reactor Job

Whenever students of history gather, the talk nearly always gets around eventually to a favorite argument, the Great Man theory of history: do great men shape events and change the course of history, or are they called into being by irresistible historical forces?

It can be assumed nothing was further from the minds of the directors of Combustion Engineering Inc. than to set up a laboratory experiment in historical determinism when they arranged late in 1958 to purchase the General Nuclear Engineering Corp. The experiment is nevertheless there. For the principal —if not the only—reason CE paid $2-million in stock for GNEC was to acquire the person of Walter H. Zinn, one of the outstanding figures in the brief history of nuclear reactors. He, it was hoped, would lead Combustion out of the wilderness and into the promised land of major reactor makers.

The Components Business

Combustion Engineering, one of the big three among manufacturers of conventional steam-raising equipment (with Babcock & Wilcox and Foster Wheeler), first got a toe into the door of the atomic world in 1946 when it sent an engineer to Oak Ridge where the first feasibility studies on generating power from uranium fission were being carried out. Soon thereafter the company received a contract for design and manufacture of liquid sodium heaters and steam generators for the nuclear power plant development then just being undertaken by the Navy's Bureau of Ships.

This was the start of a markedly successful corporate career in nuclear components, especially reactor pressure vessels and heat exchangers. Drawing on the resources and know-how of its huge metal-working shops at Chattanooga, Tenn., Combustion became a specialist in 200–300-ton steel vessels built with the dimensional tolerances of a Swiss watch. It supplied reactor vessel, shield tanks and rotating plug for both *Seawolf* and her land-based prototype, and sodium steam-generating equipment for the latter; the reactor vessel and its internals for Shippingport; the 315-ton reactor vessel, internals and rotating plug assembly for the Fermi fast breeder; three vessels and internals for *Triton* and her prototype, another for the A1W large-ship reactor prototype in Idaho, two more for the nuclear destroyer *Bainbridge;* and assorted steam generators and pressurizers, plus eight cores for the Navy.

In July 1955, Combustion became the nation's third naval reactor contractor when it was assigned by AEC to design and develop a propulsion reactor for a small submarine. The company then bought 530 acres at Windsor, Conn., where it built a nuclear engineering center including an administration office building, a string of development labs, a fuel fabricating plant and a 2-cell critical facility; nearby was built the land-based prototype, S1C, for the small submarine reactor, which went critical in August 1959. The submarine itself, *Tullibee,* was launched April 27, 1960, and is now being fitted out.

At Windsor, Combustion has invested some $16-million in facilities alone. Another $6-million went into the heavy manufacturing plant at Chattanooga for a new nuclear bay and special equipment such as a 15-million volt betatron for fast X-raying of thick plate and welds, large precision machine tools, and cranes with over 300-ton capacity. A further $8-million or more was invested in research-development work, including some $4-million on the S1C prototype, $1-million on Fermi components. This adds up to a total of $30-million CE has committed to nuclear power.

AT WINDSOR: Combustion's plant. Two new wings are now being added.

Romance (Corporate)

Nevertheless Combustion had at end-1958 no power-reactor prime contract, aside from the submarine and its prototype. It seemed therefore like a logical move for the company to become interested in GNEC. This engineering design and consulting firm had been founded in July 1956 by the brilliant Walter H. Zinn upon his retirement from the directorship of Argonne National Lab. Thanks in large part to his international reputation (and abetted by the top-notch staff he attracted around him), GNEC had a meteoric start and was sought after by many of the groups then planning or coveting a reactor, or just studying: Middle South Utilities Inc. (power prototype and full-scale plant); Venezuela (medical research); Isotope Products Co. (cobalt and process steam); Puerto Rico (power, boiling water); Univ. of Florida (training); Florida Nuclear Group (power, gas-cooled); Carolinas-Virginia group (power, D_2O); AEC (evaluation of British, French gas reactors); Germany and Cuba (power, boiling water).

The merger was consummated in January 1959, with GNEC remaining in Dunedin, Fla., as a wholly-owned subsidiary of Combustion, and Zinn moving to Windsor as CE's vice-president, nuclear. (However, since strong-minded, dominating personalities of high temperament rarely work well together as a team, Zinn has little to do with Combustion's activities for the Naval Reactors Branch of Adm. H. G. Rickover.)

Combustion now has some 800 people in the nuclear divisions at Windsor: 250 in the naval reactors division under William F. Roche, 550 working for Zinn of whom 200 are production-plant workers. There are about 400 production workers at Chattanooga, and about 35 at GNEC.

Since then CE has obtained an AEC contract to operate the SL-1 (Argonne Low Power Reactor, a 300-kwe boiling reactor at the Idaho test station); it has designed and is building what are probably history's biggest heat exchangers for the New Production Reactor at Hanford; it has designed a pressurized-water propulsion plant for a large tanker; it carried out the conceptual design for AEC's Nuclear Test Plant, to test entire cores for Army package power reactors; it designed PL-2, a 1-Mwe portable and air-transportable boiling water plant,

a scale-up of SL-1; and in its development labs it has been working on fuel-cycle projects like trying to make ceramic fuels by vibratory compaction rather than pelletizing, and trying to find ways of increasing thermal conductivity of UO_2. It is carrying out a general study on nuclear superheat for AEC. CE and GNEC are designing and will supervise nuclear construction of the BONUS (BOiling NUclear Superheat) reactor in Puerto Rico—but fabrication is to be let out on bid component by component; Jackson & Moreland is acting as architect-engineer. And it is working with the Florida group to devise a suitable fuel element.

Wanted: A Prime

But Combustion still has no power reactor prime contract. It is the only one that does not, among the seven firms generally considered leaders in the civilian nuclear power field (with Westinghouse, General Electric, Babcock & Wilcox, Atomics International, Allis-Chalmers, General Atomic).

Combustion lost valuable time—and a chance to build prestige—that it may not recover for a long time, perhaps never, when it entered the naval program as third reactor builder in 1955. One of the conditions exacted by Admiral Rickover is reported to have been that Combustion would bid on no civilian reactor jobs for three years. (As a matter of fact, CE did bid on the Liquid Metal Fueled Reactor Experiment, whereupon Rickover withdrew the S1C contract; CE had to "go back on our hands and knees," withdraw the LMFRE bid and make a number of new concessions to Rickover to get the S1C contract back.) At that time Rickover said he was going to build 400 small submarines using the S1C reactor—an alluring prospect, difficult for any company management to resist. So for some years Combustion did not bid on civilian reactor jobs. But unfortunately there will not be any more *Tullibees*. And although Combustion says it still bids on Navy core jobs, it has not had an order for well over a year.

The firm has bid recently on the Los Angeles-Pasadena improved-cycle boiling reactor (50-Mwe), the McMurdo Sound reactor (1.5-Mwe), the Small-Size Pressurized Water reactor (16.5-Mwe), and did not bid to SENA, Southern California Edison or Pacific Gas & Electric, all interested in 200+-Mwe plants. But this does not mean Combustion will specialize in small reactors. Rather, the company is interested in any proposal that does not involve excessive commercial risk.

JCAE Influence Brings McMurdo Project to Fruition; Martin Gets Contract, Shoots for March '62 Operation

As it has so often in U. S. nuclear history, the influence and determination of the Joint Committee on Atomic Energy has added another power reactor to the U. S. program. The latest was added last month when AEC selected the bid of Martin Co. to manufacture, erect and test operate a 1,500-kwe pressurized-water reactor for McMurdo Sound, Antarctica.

It was largely at the insistence of JCAE that McMurdo and two smaller reactors to be built in Antarctica were scheduled for construction. Had JCAE not intervened it is virtually certain that the Navy, which has responsibility for Antarctic facilities, would have decided on diesel plants (NU, Apr. '60, 27)—at cheaper capital costs but considerably higher operating cost.

Martin beat out Combustion Engineering and Alco Products for the McMurdo plant; AEC said cost of the plant would not exceed $3,950,678 (actual negotiated price may be something slightly less). The reactor must be ready for shipment from the U. S. by Nov. 1 next year and be in operation by March of 1962. The Martin plant is a modification of the PM-1 (portable, medium) reactor under construction for the Air Force and to be erected at Sundance, Wyo., next summer.

Byrd, Pole Reactors

A significant feature of the McMurdo bidding was the AEC request for options from all bidders for one or two more reactors for McMurdo or, possibly, Byrd Station and South Pole. AEC asked for the options to obtain some idea of savings, if any, which might accrue if identical reactors were ordered for McMurdo, Byrd and Pole (with less powerful cores, of course, for the smaller plants). On the basis of the Martin, Alco and CE option offers, AEC said a saving of no more than 10% appeared to be possible by producing a duplicate of McMurdo, with only negligible savings for a triplicate.

Under these circumstances, it was suggested, it is likely that AEC or the Navy will go out again on bid for the Byrd and Pole reactors, rather than take up the options accompanying the McMurdo bids. The Byrd reactor is scheduled for operation in March 1963, a year behind McMurdo, and the Pole is a year behind Byrd (operation in March 1964). However, AEC officials said, contracts for these are expected to be let "in the near future."

There was one problem area remaining for the McMurdo project—how to transfer the reactor to the Navy. This question arose because section 91 of the 1954 Atomic Energy Act, which provides for transfer of reactors and fissionable material to the Defense dept., authorizes such transfer for military purposes only. McMurdo will be a non-military facility furnishing power for scientific projects sponsored by the National Science Foundation and others. AEC could take the plant through its licensing procedures but this would be time consuming; the alternative under consideration was amendment of section 91 to permit transfer for non-military use.

FIRST POWER PLANT FOR ANTARCTICA will be located at this site (bottom in photo) at McMurdo Sound. It will deliver power to the Naval Air facility shown above it.

Foto courtesy U. S. Navy, Martin Co.

REACTOR NEWS

AEC WILL BUILD IMPROVED-CYCLE OMR

AEC plans to proceed with construction of a 75-Mwe improved-cycle organic prototype reactor, and is expected to select an architect-engineer for the project within the next few weeks. The project has not yet been formally approved by the Commissioners. AEC's reactor staff had been studying whether to proceed with construction at an AEC site since the utility industry had failed to sponsor the prototype earlier this year. Major consideration was whether fuel technology on the proposed core, with sintered aluminum power, was sufficiently promising to support a full-scale prototype. This is one of two organic reactors provided in the fiscal-'60 reactor program (see table NU, Feb. '60, 18); the other, EOCR (Experimental Organic Cooled Reactor, ex-OMRE-2), is already under construction at the Idaho reactor test center. This $6-million, 20–40-Mwth facility, to be completed in late 1962, will be operated by Phillips Petroleum Co.

DRESDEN TO GET STAINLESS CORE

Second core for the 180-Mwe Dresden boiling reactor will use stainless steel, instead of zircaloy, cladding. The change will require an increase in enrichment from 1.5% to 2.7%. General Electric nevertheless hopes for 8,000–10,000 Mwd/ton burnup with the first core, 12,-000–15,000 with the second. It expects the first core to last about a year before center elements start having to be replaced. GE fears hairline cracks, such as appeared last winter before Dresden's startup (NU, Jan. '60, 18), might, under long exposure, lead to major defects. Earlier GE had proposed a stainless- instead of zircaloy-clad core to SENN; the question is still under study.

FLY TWO A-PLANE TYPES IN 1965: BRANCH

Two nuclear-propelled planes flying in 1965—both a direct-cycle and an indirect-cycle type: this is the aim of Aircraft Nuclear Propulsion Chief Gen. Irving Branch. The ANP boss told NUCLEONICS he wanted to make a selection between the competing systems on the basis of actual flight-test experience. (Latest architect's sketches of the two planes: NU Wk, 4 Aug. '60, 3.) Meanwhile, General Electric, developer of the direct-cycle engine, is making progress at the Idaho reactor testing station on construction of its new experimental aircraft reactor, and is "considerably further along," Gen. Branch said, than is Pratt & Whitney's indirect-cycle reactor at its CANEL labs near Middletown, Conn. GE's reactor, P140-E, is fifth in a series of reactor-and-jet-engine units; it embodies a change in core configuration over its predecessor, Gen. Branch said, although it uses the same fuel elements. (GE is also continuing work at Idaho with HTRE-2 [High Temperature Reactor Experiment] "because it can use ceramic fuel.") P140-E will have a power level "more than 100 Mwth, a very crude ball-park figure," but despite good progress, it will be "a long time before it goes critical." It owes its changed core configuration to Administration insistence on a "militarily useful" [supersonic] nuclear plane (NU, Sept. '59, 28).

FLORIDA REACTOR POSTPONED 1–2 YEARS

Construction of the Florida West Coast reactor has been postponed one–two years as result of a reorientation of the project's research and development program, to focus on solving technical hurdles to use of beryllium as cladding material, instead of stainless steel. The move was not unexpected, having been foreshadowed by apprehensions on the part of the project's sponsors regarding rising power cost estimates (NU, July '60, 28). Sponsors are the Florida West Coast Nuclear Group, which was to start building the 50-Mwe gas-cooled, pressure-tube D_2O-moderated reactor now if power cost were not more than 1½ times conventional power cost; and East Central Nuclear Group, which is administering and sharing the cost of the research-development program. The reorientation will also seek to bring present contractual arrangements more in line with AEC's third round rules; this would eliminate some of the contingencies in the present contract and give greater assurance that the prototype plant would, eventually, be built.

JAMESTOWN SITE TURNED DOWN AGAIN

The Advisory Committee on Reactor Safeguards has again advised against building AEC's Small-Size Pressurized Water Reactor on the site proposed by the city of Jamestown, N. Y. This is the second rejection of the Jamestown site; the exclusion area, held by ACRS on first review to be too small, was increased to 1,500 ft radius; this still failed to meet AEC's suggested 2,000 ft radius "if possible." AEC's second choice as publicly-owned utility partner is Dairyland Power Cooperative of LaCrosse, Wis. Dairyland's original site was also found wanting by ACRS, but it has since suggested alternatives.

AMONG THE FUEL FABRICATORS

A $3.7-million contract for **ramjet fuel elements** went to Coors Porcelain Co., Golden, Colo. The elements will be used in Tory II-C, second of the ramjet test series. Tory II-A, with fuel by Livermore and GE, is scheduled for first tests in November. The big contract, expected to run 2–3 years, marks Coors' entry into the fuel element business; it has done other nuclear work, including sealing of active wastes in ceramics . . . General Electric invited **zirconium fabricators** to a seminar, called on them for help in developing cheaper, better zirconium alloys. GE laid down specifications for a zircaloy to be used in high-performance boiling reactors . . . Olin Mathieson got its **first commercial core contract**, to make second cores for the Ft. Greely, Alaska, SM-1A and Camp Century, Greenland, PM-2A Army package power reactors. Total price bid was $267,323: delivery due dates are Dec. 1, 1960, and March 1, 1961. OM had previously made fuel only for the Navy. The fully-enriched stainless-UO_2 elements are Olin's first cermet job . . . NUMEC got a $500,000 contract to produce **high-purity hafnium crystal bars** from sponge for the naval reactors program.

NUCLEAR NAVY NEWS

The 12th and 13th A-subs passed their sea trials: *Scorpion*, first of *Skipjack's* five sisterships, and *Robert E. Lee*, third Polaris-firing sub . . . Two days after first tests, by *George Washington*, of submerged firing of Polaris missiles had scored a resounding success, the Navy awarded construction contracts for five Polaris subs just authorized by Congress barely a month earlier. Two went to Electric Boat div., General Dynamics ($60,113,000 hull cost, excluding reactors, for the pair); Newport News Shipbuilding & Dry Dock Co. got one for $32,405,000 maximum (to be negotiated); Mare Island and Portsmouth navy yards got one each. These are of the new "616" or *Lafayette* class—third generation of Polaris subs, believed to be designed to fire the improved 2,500-mile Polaris missile. The quintet brings the Polaris fleet to 14, completed, building or ordered . . . *Enterprise*, the eight-reactor supercarrier—world's largest ship—will be launched Sept. 24 at Newport News.

WORLD NEWS

Ispra Agreement Finally Ratified

By 248 to 125, Italy's Parliament at end-July finally ratified the Ispra agreement leasing the big nuclear research center on Lake Maggiore to Euratom for 99 years. The agreement was signed just a year earlier (July 22, 1959: NU, Sept. '59, 30); Parliament's dilatoriness in ratifying it has been a thorn in Euratom's side. Euratom at once announced that the first of 500 nuclear scientists and technicians from six countries—vanguard of some 1,500 expected to be employed by Euratom at Ispra by 1962—would start arriving at once. Euratom said the importance of the center to it was shown by the fact that Euratom will spend $40-million in the next two years on extensions to the $20-million plant. Italy is slated to pour in another $15-million. Ispra's major functions will be work on power reactor technology, instrument research, raw- and processed-materials research, and training of scientists. Current work underway on neutron and solid-state physics, metallurgy, and reactor performance measurement, will continue. One of the new installations is to be a high-performance computer center for joint use by the Italian national nuclear program and that of Euratom.

Italian A-Law Passed, CNEN Set Up

After years of argument, Italy's Parliament has passed a basic nuclear law—but in abridged form. The Colombo bill sets up an Italian AEC: the CNEN (National Commission for Nuclear Energy) in place of CNRN which dealt only with nuclear research; it will be an arm of the Industry and Commerce Ministry. The bill appropriates $120-million for nuclear research for 1960–64, but sidesteps mention of third-party liability and of the explosive issue of the roles of the government and private industry in nuclear powerplant construction and operation, both temporarily shelved "because of the political situation."

Seven Nations Set Up European Forum

Foratom, a seven-nation European atomic forum, has been founded by the national nuclear associations of the six Euratom countries and Switzerland. The Europe-wide organization, Forum Atomique Européen (or Foratom for short), will have headquarters in Paris. Purpose is to stimulate growth of peaceful uses of atomic energy by keeping industry and the public informed. It will publish an information bulletin and plans a congress in Paris in 1962. First president is Prof. Carlo Matteini, head of the Forum Italiano dell'Energia Nucleare; he will be followed in 1962 by Henri Ziegler of France's ATEN (Association Technique pour l'Energie Nucléaire), and in 1963 by Hans Reuter of Deutsches Atomforum. Britain's position is uncertain as no national body exists.

Sixth U. K. Report Sees Steady Progress

Britain's civil reactor cutback (NU, Aug. '60, 30) is a change in pace, not a change in policy, U. K. AEA chairman Sir Roger Makins declared in presenting the Authority's sixth annual report. In fact, budget for the coming year—$261.2-million—is a slight increase over the current year. Receipts from AEA's commercial operations came largely from sale of fuel slugs to the Central Electricity Generating Board's civil nuclear power stations, and amounted to $56-million. Isotope sales, $3-million, increased by 25%; over half the isotopes were sold abroad. Steady progress without sensational developments is the main theme of the report.

Highlights: Thermal output of the Calder Hall and Chapel Cross reactors has been uprated 15% above design rating, and over-all operational availability increased to 80% including scheduled refueling operations (an increase of 50%). It has been found possible to raise fuel element operating temperature without loss of reliability: an increase from 765° to 785° F is scheduled, with others to 825° to follow. In a major experiment to establish burnup data, the fuel charge was left in one Calder reactor; by March this year average burnup of 700 Mwd/metric ton—and maximum of 2,000—had been obtained. AEA now believes the 3,000 Mwd/metric ton design figure will be achieved. Altogether 200,000 elements have been irradiated by AEA; failure rate is still below 0.1%.

France's G-2 Back in Operation

G-2 went back on the line after a coolant leak at the loading face had forced shutdown (NU, Aug. '60, 30). French officials said the big reactor was started up just eight days after the leak occurred.

GLEEP Overhauled

Western Europe's first reactor, Harwell's GLEEP (Graphite Low Energy Experimental Pile) was extensively overhauled after 13 years' operation. The graphite-moderated, air-cooled, 3-kw research reactor first went critical Aug. 15, 1947 (NU, Jan. '51, 3); it is almost a contemporary of Oak Ridge's similar X-10, operating since November 1943. GLEEP was modernized, its instrumentation completely renewed and partly transistorized, and a new control room built, after its 33 tons of fuel (canned UO_2 pellets and bare uranium bars) had been unloaded in an argon atmosphere. The old fuel went to Windscale for reprocessing; GLEEP has been recharged with Al-clad natural-U slugs. GLEEP is used mainly for materials and components testing.

OEEC Liability Convention Signed

Ten countries signed the OEEC third-party liability convention within a fortnight after it was opened for signature. Austria, Britain, Denmark, West Germany, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland, have signed; seven of the remaining eight OEEC nations are expected to sign by Oct. 31, deadline for original contracting parties; Italy has indicated unwillingness to restrict liability to the operator. The convention for all practical purposes frees suppliers from any liability for damages resulting from a nuclear accident. All liability is channeled to operators of nuclear installations, and the liability is absolute. Liability limit is set at a maximum of $15-million per accident, but individual governments may set lower limits down to $5-million—although most are not expected to do so. The convention requires operators to carry insurance or other financial security up to the limit. Time limit for filing claims is ten years after an accident. The convention covers all reactors (except propulsion), isotope separation plants, irradiated fuel reprocessing plants, and fuel fabricating plants (except those for natural U). It does not cover mining activities, research laboratories (except those with reactors), and industrial users of isotopes. Five ratifications are required.

First Nuclear Shipbuilding Rules

Lloyd's Register of Shipping has published the first nuclear ship classification rules. Provisional, they have been framed primarily for guidance in a changing, developing field. Detailed requirements are laid down for materials, longitudinal strength of hull, pressure vessels and components, reactor engineering and control, and provision of emergency power.

NEWS IN BRIEF

Pitzer Succeeds Johnson as GAC Chairman

The 6-year terms of two members of AEC's General Advisory Committee, Chairman Warren C. Johnson of the Univ. of Chicago and Jesse W. Beams of the Univ. of Virginia, expired Aug. 1. Johnson was succeeded as GAC chairman by Kenneth S. Pitzer, dean of chemistry at the Univ. of California, Berkeley. President Eisenhower will name a successor to Beams.

AEC's Compliance Div. Assumes Facility Inspection

Responsibility for the inspection of reactors and other facilities licensed by AEC has been assigned to the Commission's Compliance div., effective Aug. 1. Facility inspections will be supervised by Peter A. Morris, formerly of the Inspection div., as deputy to Compliance div. director David Low. The Inspection div. retains authority over inspection procedures and inspection of non-licensed facilities. It will also have responsibility for independently inspecting licensed facilities, if necessary. The Compliance div. now has responsibility for all licensee inspections.

Lockheed, Martin Selected for NASA Rocket Studies

Lockheed Aircraft Co. and Martin Co. were selected by the National Aeronautics and Space Administration last month to carry out flight-test studies for the nuclear rocket (NU, July '60, 24). Each gets a $100,000 NASA contract (winning over ten other bidders) but each is expected to contribute several times that from its own funds, according to NASA. To get "a varied point of view," NASA said, it has asked each contractor to cover the same ground: investigate the possibilities and problems of field-testing nuclear rockets for 3–4 launch situations (stationary ground test, second-stage launch from a chemical rocket into the sea, orbital startup and self-launch, where the rocket is first stage).

On completion of the 6-month studies, NASA expects to schedule detailed engine design, provided the Kiwi reactor test series proceeds without major setback; hardware development would follow engine design.

AEC Reduces Price for Carbon-14 by 27%

For the second time in a year, AEC has reduced its price for carbon-14, which is produced and marketed by Oak Ridge National Laboratory. Effective July 1, the price was dropped from $13 to $9.50 a millicurie—a 27% reduction; the price had been dropped by 50% on July 1, 1959.

House Appropriations Unit Begins ANP Inquiry

A Congressional investigation of the Aircraft Nuclear Program (ANP), sponsored by the Defense and Public Works subcommittees of the House Appropriations Committee (NU, July '60, 22), has gotten under way in Washington. An investigatory team led by a member of the Federal Bureau of Investigation received its first briefing on the program at AEC late in July. Appropriations Committee sources said there was nothing unusual in the inquiry's being led by an FBI official. The Committee has two separate staffs—administrative and investigatory—and the latter is traditionally headed by an FBI man on loan for two years. He, in turn, is free to bring in other FBI personnel to conduct, or help to conduct, a specific inquiry like that of ANP. The investigatory team is completely incommunicado during its inquiry—even to Committee members. It will file a report with Committee Chairman Clarence Cannon (D-Mo.) upon completion of its work late this year or early next; the report may, or may not, be published when the Committee completes next year's hearings on the ANP budget (fiscal 1962, beginning July 1, 1961). Government officials said the inquiry was administrative—rather than technical, presumably dealing with such questions as duplication of effort, funds spent to date, and possible cost of proceeding with two approaches right through flight test (*related story page 25*).

Martin Offers to Lease Curtiss-Wright Hot Cells

Anxious to proceed with its strontium-90, isotopic-power generating program, Martin Co. has offered to lease from Curtiss-Wright its hot-cell complex at Quehanna, Pa., where the nuclear facility has been shut down (NU, July '60, 28). Martin needs hot-cell capacity for the fabrication of isotopic generators such as the device it is building for remote weather-station use and the much larger devices the Navy and Coast Guard are seeking for navigational aids (*page 28*). It had to drop its plan for building a megacurie processing facility at its Baltimore headquarters when AEC indicated the exclusion area was too small. C-W's nuclear-research building at Quehanna houses both a research reactor (now shut down) and five hot cells—three rated at 10 million curies, two at 100,000. The company has indicated it would like to lease the entire facility (and has been showing it to other firms) but was giving some thought to sharing the building—reactivating the reactor for its own use, leasing the hot cells to Martin.

Business Briefs: Industry Bids on Three Projects

In a mid-summer flurry of bidding activity, the nuclear industry was either bidding or awaiting action on bids for at least six important projects:

1. NASA. For a low-power "mock-up" of the National Aeronautics and Space Administration's Plum Brook research reactor, Sandusky, Ohio, there were six bidders. NASA asked bids for the basic critical assembly and for the assembly with modifications. Bids on the basic assembly (NASA providing pool and fuel elements): Lockheed Aircraft Corp., $495,655; Kaiser Electronics, $566,637; Baldwin-Lima-Hamilton, $624,723; Bendix, $632,801; Curtiss-Wright, $706,960; and Allis Chalmers, $837,340.

2. Shippingport. Four bids were received for two inconel steam generators AEC might buy to replace generators which developed stress-corrosion-caused leaks. Babcock & Wilcox and Foster Wheeler were the two low bidders for supply alone and for supply-and-testing—bidding in a range around $500,000 for each generator. Combustion Engineering and Westinghouse were both higher at more than $700,000.

3. Army Barge-mounted Reactor. The Corps of Engineers was to get bids Aug. 18 on a 10-Mwe nonpropulsion reactor for a Liberty ship (NU, Aug. '60, 22).

4. National Bureau of Standards. NBS asked bids by Aug. 15 for detailed design of a 10-Mw, heavy-water research reactor for completion in about three years. Architect-engineer will be selected first.

5. Antarctic Reactor. Martin's bid was selected after a delay for re-evaluation of reliability by Argonne National Laboratory (*page 24*).

6. Cobalt Irradiator. A total of nine bids were submitted to Walter Reed Medical Center to supply a cobalt-60 irradiator for mice and guinea pigs (NU, Aug. '60, 32). In the range $20–24,000 were, in order: U. S. Nuclear Corp., Atomic Energy of Canada, AMF Atomics, National Lead, Budd Co. and Radiation Applications, Inc. Other bids were submitted by Curtiss-Wright Corp., Ameray Corp. and Ray Proof Corp.

RADIATION NEWS

AEC Extends Isotope Contracts, Awards New Ones

In a burst of activity as it completed its 1960 fiscal year (June 30) and went into fiscal '61, AEC's Office of Isotope Development extended several contracts under its Isotope Development Program (IDP) and awarded quite a few new ones. Two contracts with particularly interesting economic aspects went to Radiation Applications, Inc.: 1. a comparative-cost study of nuclide and electron radiation for graft copolymerization; and 2. development of techniques for reducing radiation requirements for cross-linking plastics. The graft copolymerization area was selected for economic comparison because dose requirement is in a fairly low range (50–100,000 rads); cross-linking of plastics, on the other hand, requires as much as 15 million rads, where machine radiation is felt to be considerably cheaper than nuclide radiation. RAI will use polyethylene and nylon as its "backbone" materials, grafting onto these four monomers: styrene, styrene acrilonytrile, methyl acrylate and vinylidene fluoride. RAI will use its own cobalt-60 source and rent time on radiation machines to develop data on dose rates, temperatures, monomer and copolymer concentrations and pretreatment of monomer and polymer.

The second program—reducing dose requirement—will center on an attempt to jell polymer and monomer mixtures, including the mechanism of radiation cross-linking in polymer-polyfunctional monomer systems. The addition of monomer to polymer may sharply reduce the radiation required for cross-linking. Other IDP contract actions:

1. Universal Match Corp. Investigation of the effects of ionizing radiation on sedimentation of sewage, $49,-250. Can radiation increase the rate and/or amount of sedimentation by increasing the size of agglomerates or by coagulating sols or colloids?

2. Battelle Memorial Institute. Extension of work on radiation-induced graft polymerization, $63,000. Emphasis on the effects of structural factors on the radiation stability of polymethacrylates, with the hope of developing data basic to the radiation-grafting of other polymer systems.

3. Armour Research Foundation. Radiation synthesis involving halogenated compounds, looking toward the creation of useful chemical compounds and knowledge basic to radiation chemistry and radiation processing, $49,900.

4. Air Reduction Co. Promotion of chemical reactions using magnetic fields in conjunction with beta radiation, using an electrical field to restore energy to electrons produced by krypton-85, $42,000.

5. Technical Research Group. Synthesis of semiconductor materials by radiation induced reactions, an extension of an effort to produce pure silicon by the radiation-induced decomposition of silane, $38,400.

6. Catholic Univ. The use of a pulsed-neutron source and a pulse-height analyzer to detect trace stable isotopes manufactured into dynamite as additives. This effort was scheduled at the request of the Federal Aeronautics Administration, which has been attempting to find a detection system for bombs carried aboard airliners by passengers.

7. Georgia Tech. Radiation-induced cyanogenation of organic compounds—high-precision determination of yield values for reaction products.

8. Evans Research and Development Co. Extension of its contract for development of a beta-particle back scatter technique for determining particle size, $48,000.

Commerce Dept. Begins Nuclear Instrument Survey

Officials of the Commerce dept. said last month they expected, before September was out, to begin the first federal statistical survey of the nuclear instrument field. It will be handled by the department's Business and Defense Services Administration, in cooperation with the Census Bureau, and will cover calendar 1959. The questionnaire will ask 1959 data on shipments (unit and value), transistorized units (proportion to nontransistorized units) and plant capacity for defense-mobilization purposes; it will go to 653 organizations, all of whom must fill out and return it under federal law. The census is a one-shot effort, its continuance dependent entirely upon the industry's desire to have it continued on an annual or other periodic basis; it would not be continued unless industry pressure for it develops, according to BDSA.

Unusually Strong Demand Develops for Isotopes

The need of military and commercial customers—and AEC itself—for substantial quantities of radioisotopes primarily for isotopic-powered generators has put heavy pressure on AEC to meet delivery schedules. This was the situation last month as AEC's Fission Product Pilot Plant (F3P) was readied for a return to service after a nine-month shutdown (NU, Aug. '60, 32). During the shutdown, the plant's capacity was boosted and it was modified to permit simultaneous separation of its five products—cesium-137, strontium-90, promethium-147, cerium-144 and technetium-99; however, even as upsized and in full operation, F3P cannot meet the strontium demand and will be pressed to meet the demand for cerium-144 and cesium-137 (this, for teletherapy sources). The demand:

Strontium. The Navy and Coast Guard have asked AEC's Aircraft Reactors branch and Office of Isotope Development to deliver four prototype isotopic-power devices for experimental use as navigational aids. Two will be rated at 10 watts (47,000 curies each of strontium titanate) and two at 60 watts (280,000 curies); each service will get a large and small device. AEC will fabricate the smaller prototypes but will probably invite Martin Co. or some other firm to make the larger devices. Meanwhile, the weather telemetry device Martin is to build for AEC and the Weather Bureau will require some 20,000 curies strontium titanate (5 watts). AEC is meeting this total strontium requirement of more than 650,000 curies by assigning half of it to F3P and half to Hanford, where several existing hot cells will be modified for strontium separation.

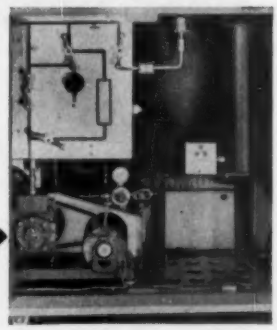
Cerium-144. The fueling of SNAP 1-A (NU, July '60, 27), the 125-watt generator under development for space auxiliary power, requires 880,000 curies of cerium oxide by early next year.

Cesium-137. Current order backlog for cesium totals 130–150,000 curies, with Picker X-Ray Corp. negotiating for another 100,000 curies. Most of this demand is for teletherapy sources (1,500–2,000 curies each).

13 Bid for NASA Radiation, Custodial Contract

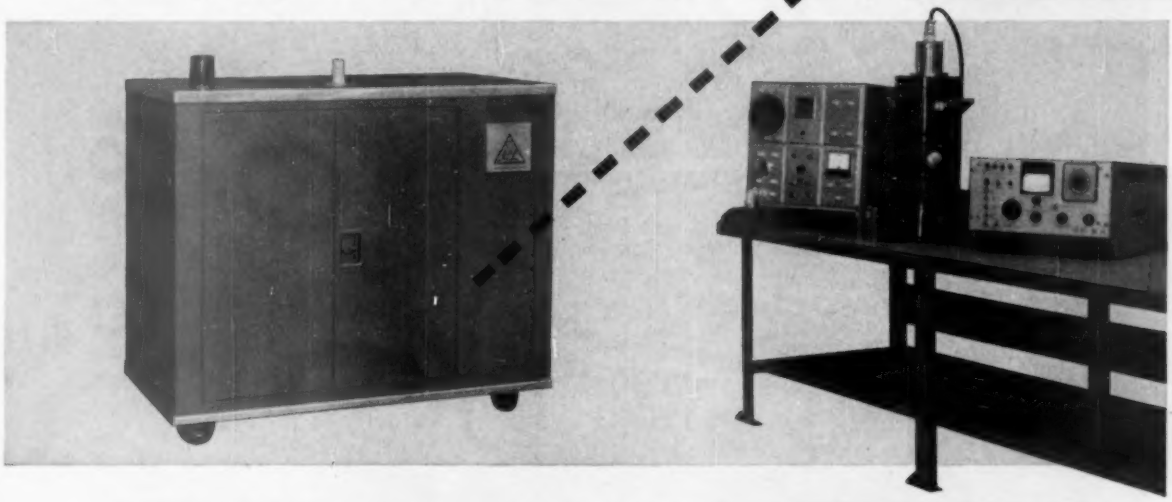
The National Aeronautics and Space Administration was expected late in August or early in September to select from among 13 bidders an industry manager for all radiation protection, waste disposal and janitorial services for the Plum Brook research and test reactor, Sandusky, Ohio. The cost-type contract was estimated to cover about $500,000 in annual managerial and radiation-protection services, including about $300,000 in the radiation area. It will be renewed year-by-year.

NEW DOUBLE-DUTY RCL NEUTRON ACTIVATOR produces radioactive isotopes and performs non-destructive complex analysis in minutes



The RCL Neutron Activator, which consists of a wheel-mounted source cabinet and a control chassis, generates 14.1 Mev. neutrons by the H^3 (d,n) He^4 [Tritium (Deuteron, Neutron) Helium] reaction. The target is guaranteed to provide a minimum of 10^8 neutrons per second, for at least 100 hours. It is easily replaced and never needs cleaning. Neutron output is pulsed and may be continuously varied from 10 to 100 pulses per second.

Pictured Below:
Neutron Activator Source Cabinet, RCL 128 Channel Scaler-Analyzer, Dual-Purpose Iron Shield and Detector, and Neutron Activator Control Chassis. To operate, appropriate shielding is required for source cabinet.



OPENS NEW AVENUES OF RESEARCH

The RCL Neutron Activator System has a broad spectrum of uses, extending from the production of radioactive isotopes and neutron activation analysis to the study of transients in reactors and neutron multiplying systems. It enables the scientist to economically produce in his own laboratory many isotopes which normally cannot be used because of short half-lives.

Neutron activation analysis greatly simplifies and shortens the time required for standard qualitative and quantitative chemical analysis techniques. In addition, since it is non-destructive, it may be readily automated for routine production control.

The RCL Neutron Activator can determine 1000 ppm of oxygen or 500 ppm of copper in a 1 gram sample. Sensitivity increases almost linearly as sample mass increases. For example, in a 200 gram sample as little as 10 ppm of oxygen can be determined non-destructively. Most elements in the periodic table can be quantitatively determined with this technique.

FASTER, MORE EFFICIENT SAMPLE ANALYSIS

The spectra above show the presence and relative amount of copper in an aluminum-copper sample. These spectra are typical of the results obtained in sample analysis when RCL's complete Neutron Activation Analysis system is used.

A 54 gram aluminum sample was placed atop the neutron generator target and irradiated for three minutes. The sample was then transferred to the NaI detector inside the iron shield. One minute counting time yielded two photopeaks; containing approximately 15,000 counts @ 0.843 Mev. and approximately 4,500 counts @ 1.05 Mev.

The procedure was then repeated with a 64 gram aluminum and copper sample (approx. 10 gram Cu. and 54 gram Al.). The gamma ray spectrum then showed a third photopeak of approximately 9,000 counts, due to copper, at 0.511 Mev.

See RCL Neutron Activator
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Results of AI's work have been demonstrated in projects for the AEC which include the Organic Moderated Reactor Experiment at the National Reactor Testing Station in Idaho and the Sodium Reactor Experiment at the company's field laboratory. Additionally, AI built and is operating SNAP II, a 220 pound prototype reactor to produce three kilowatts of electricity for space vehicles.

Atomics International is also building large power reactors for electric utilities in Ohio and Nebraska under AEC programs. Studies are underway for other power reactors in the United States and Europe. Research reactors have been built by AI for Denmark, Germany, Italy, Japan, Puerto Rico and several sites in the United States.

For details contact: ATOMICS INTERNATIONAL, Canoga Park, California, U.S.A. Cable address: ATOMICS.

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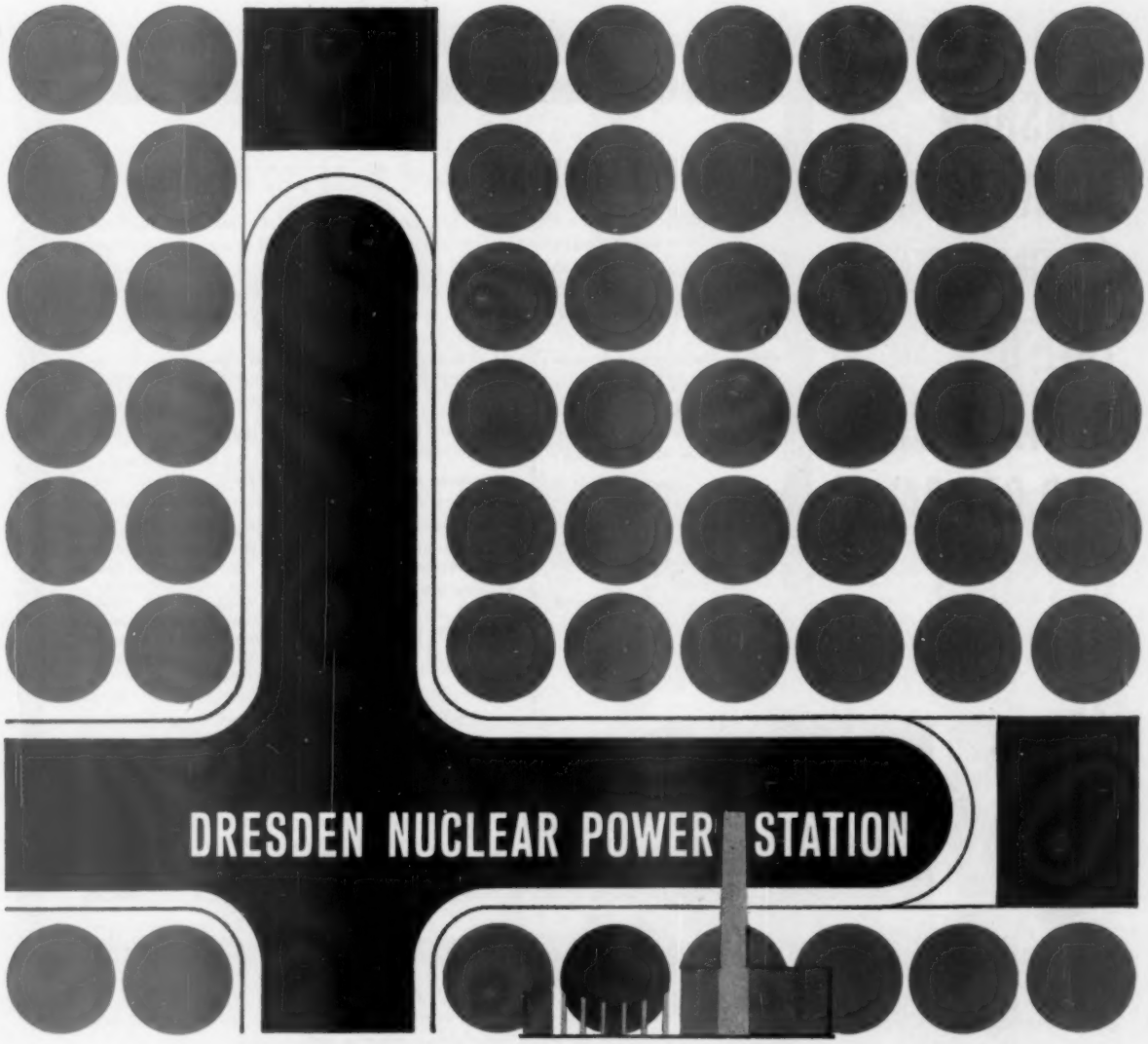

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- 19 ft. in diameter, 33 ft. high, welded of Type 304 stainless steel
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- All material subject to ultrasonic inspection; all welds inspected radiographically, also with dye penetrant and helium leak detection equipment

Reactor containment vessel

- 21 ft. in diameter, 36 ft. high
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Loading face shield shell of Hallam reactor being check-fitted to upper cavity liner

Radiography inspection at B-L-H's Industrial Equipment Division of weld joints in lower shell course of containment vessel for the Hallam, Nebr., nuclear reactor designed by Atomics International

BALDWIN · LIMA · HAMILTON

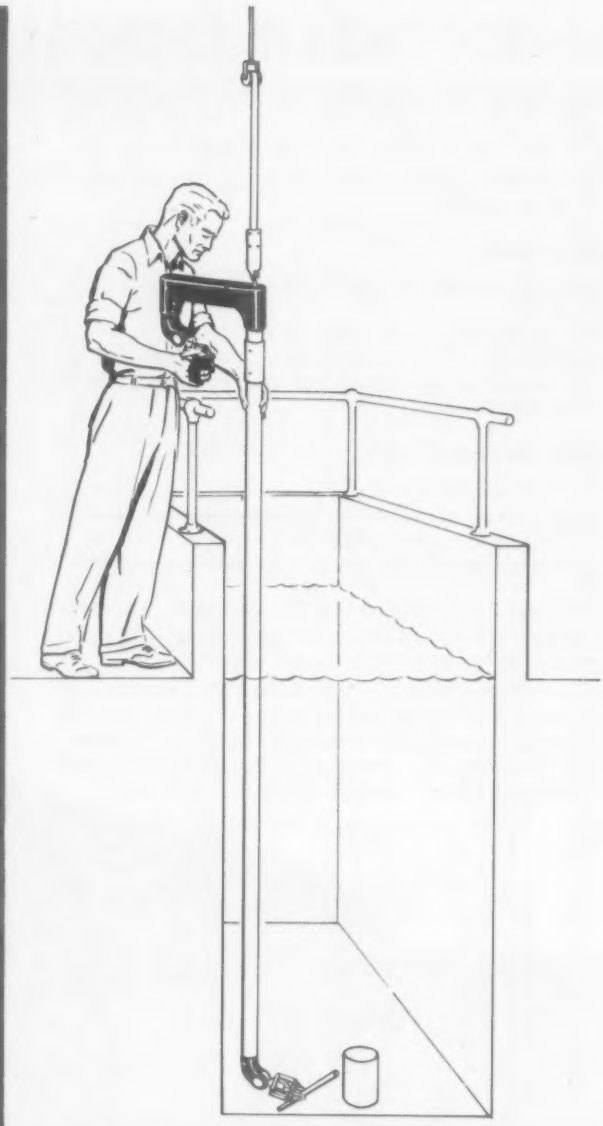
Industrial Equipment Division · Philadelphia 42, Pa.

UNIQUE...

simple and versatile underwater manipulation

Central Research Laboratories'

model B canal manipulator



If your operation has required grappling and fishing at the bottom of a canal or pool, Central Research Laboratories' Model B Canal Manipulator may be the new tool for you. Master-Slave Manipulator type ambidextrous handle, wrist joints, and tongs are coupled by alloy tapes passing through a cross-over housing and long vertical tube. This makes possible dexterous underwater manipulation. All submerged components are stainless steel for maximum corrosion resistance.

Wrist Joint and Tong Motions

The wide range of wrist-joint and tong motions insures deft and adroit handling of large and small objects. Squeeze motion is 3½ inches with an elevation rotation of 168° going from 38° back of vertical to 40° above horizontal. Twist rotation is 360° minimum at ends of elevation range, 720° when the tong is pointed 45° downward.

Azimuth rotation and X, Y, and Z translations are provided by gross movement of the vertical support tube. A constant force spring suspension supports the manipulator in the canal or pool.

For further versatility, the Model B Canal Manipulator may be equipped with standard or special purpose interchangeable tongs of either the RCD-447-100 or SRL-IIA type. Vertical tubes of desired length are available to meet most requirements.

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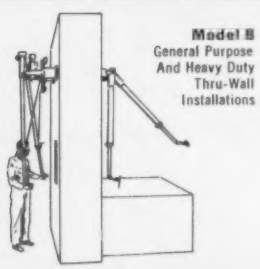
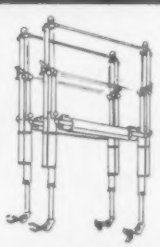
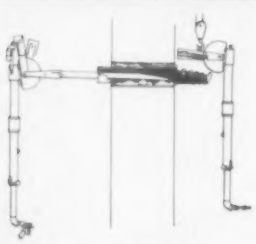


Model B
General Purpose
And Heavy Duty
Thru-Wall
Installations

Model 7
Restricted Space Installations



Model 4
Over-Wall Installations



Model A Sealed

For further information on Central Research manipulators, accessories, or hot cell design problems, write:

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laboratories, inc.
Red Wing, Minnesota Dept. 111

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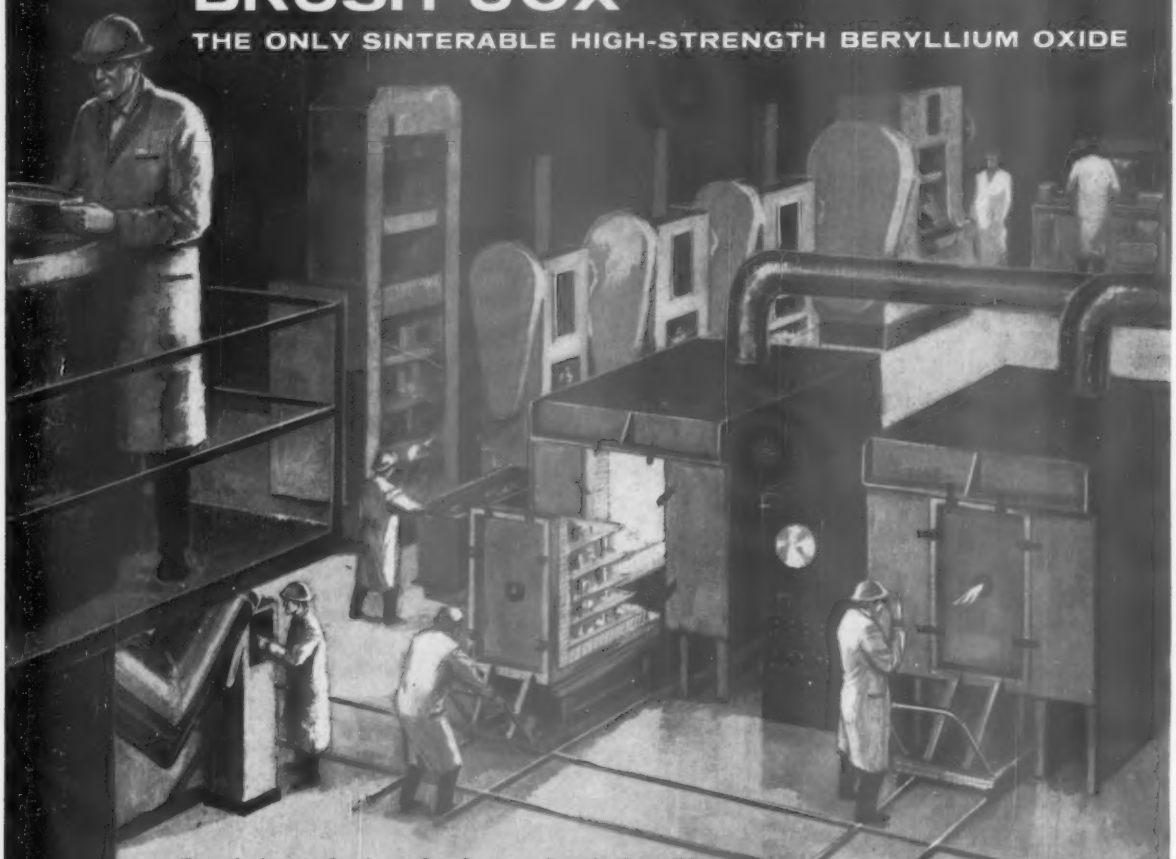

Brush is producing the first and only beryllium oxide that is both sinterable and 99.95+% pure. This combination means that manufacturers of nuclear, electronic, and aero/space components can now mass produce ceramics taking full advantage of beryllium oxide's remarkable properties.

BeO is an excellent reflector and moderator of neutrons. Its unique thermal properties include room temperature conductivity superior to most metals. It has good strength, a melting point of 4658° F., and is inert to chemical attack.

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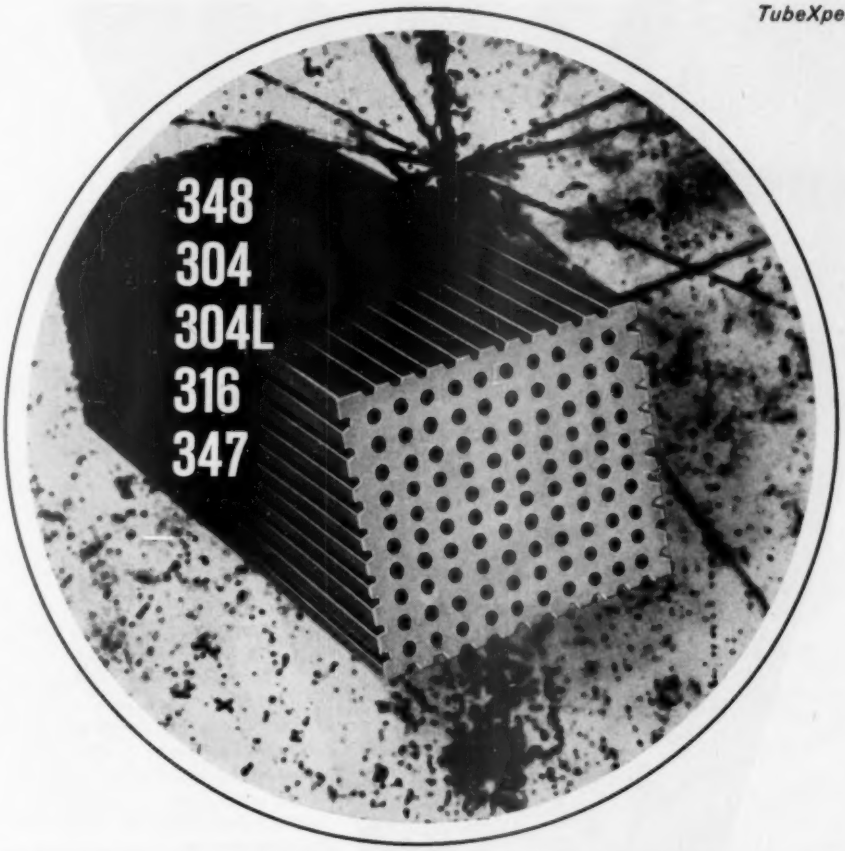
Any shape that can be fabricated by standard ceramic production methods can be produced in UOX® beryllium oxide.

THE BRUSH BERYLLIUM COMPANY



Superior now offers 5 different analyses of stainless tubing for fuel element cladding

Before selecting tubing for fuel element cladding in nuclear reactors, consider the stainless types now offered by Superior. Important characteristics are listed in the table, but there are other important advantages, too. Closer tolerances can be maintained than with such materials as zirconium or columbium and their alloys. Better surface finishes are available. And higher reliability in chemical composition, availability and fabrication into the basic mill forms needed for producing small-diameter tubing is possible.

Superior Specification STC-102 outlines the quality and technical requirements of Nuclear Quality Fuel Element Tubing in these austenitic stainless steels. Write for your copy today. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

TYPE	REMARKS
348	1. Good strength at elevated temperature 2. Low neutron absorption characteristics 3. Stabilized against injurious carbide precipitation 4. Most widely used analysis for this purpose
304	1. Most economical of all alloys listed 2. Strength at elevated temperature good, but not as strong as 316, 347 and 348 3. Good for all-around applications 4. Excellent ductility and fabricability
304L	1. Excellent welding characteristics 2. Best ductility, fabricability 3. Less expensive than 316, 347 and 348 4. Lowest strength at elevated temperature of alloys listed
316	1. Best strength at elevated temperature 2. Excellent corrosion resistance in reactor coolants 3. Good fabricability 4. Creep strength best of 300 Series
347	1. Good strength at elevated temperature 2. Neutron absorption characteristics generally higher than those of 348 3. Stabilized against injurious carbide precipitation 4. Less expensive than Type 348

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All analyses .010 in. to ⅜ in. OD—certain analyses in light walls up to 2½ in. OD

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In 1952 Pioneer joined with other groups, all reporting to the Atomic Energy Commission, for constant study of atomic energy application. Today Pioneer is qualified as a consultant to industry in the application of atomic reactor systems to the generation of electric power. Presently, Pioneer is acting as architect-engineer and supervisor of construction of the 66,000 kw commercial atomic power plant shown here. Allis-Chalmers Mfg. Co. is the prime contractor. Scheduled for 1962 completion, the plant, for the Northern States Power Co., will be known as the "Pathfinder".

Organized as Central Utilities Atomic Power Associates, these utilities will share in the research and development costs: Northern States Power Co., Central Electric and Gas Co., Interstate Power Co., Iowa Power and Light Co., Iowa Southern Utilities Co., Madison Gas and Electric Co., Mississippi Valley Public Service Co., Northwestern Public Service Co., Ottertail Power Co., St. Joseph Light and Power Co., Wisconsin Public Service Corp.

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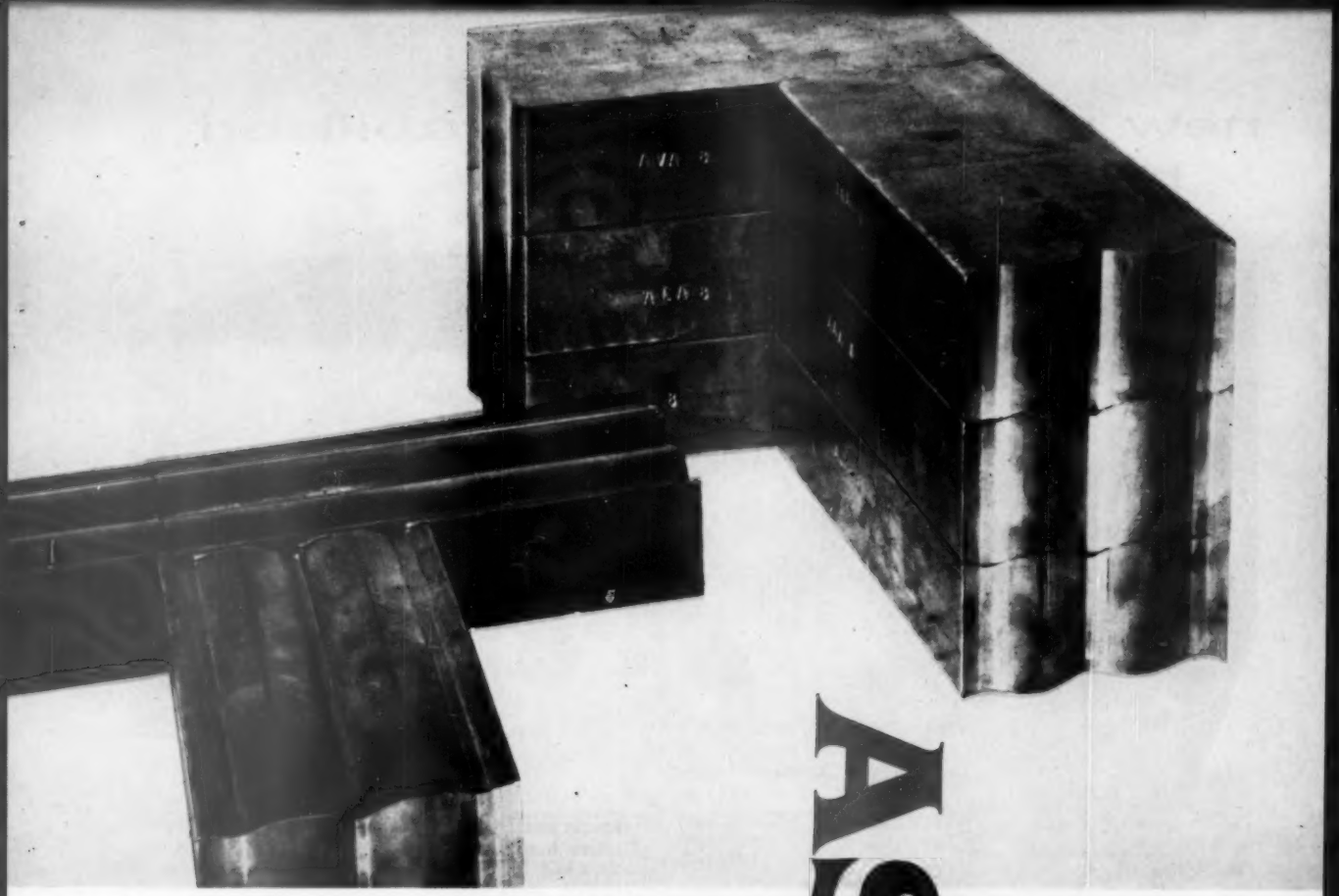
Sketch of "Pathfinder" commercial atomic power plant



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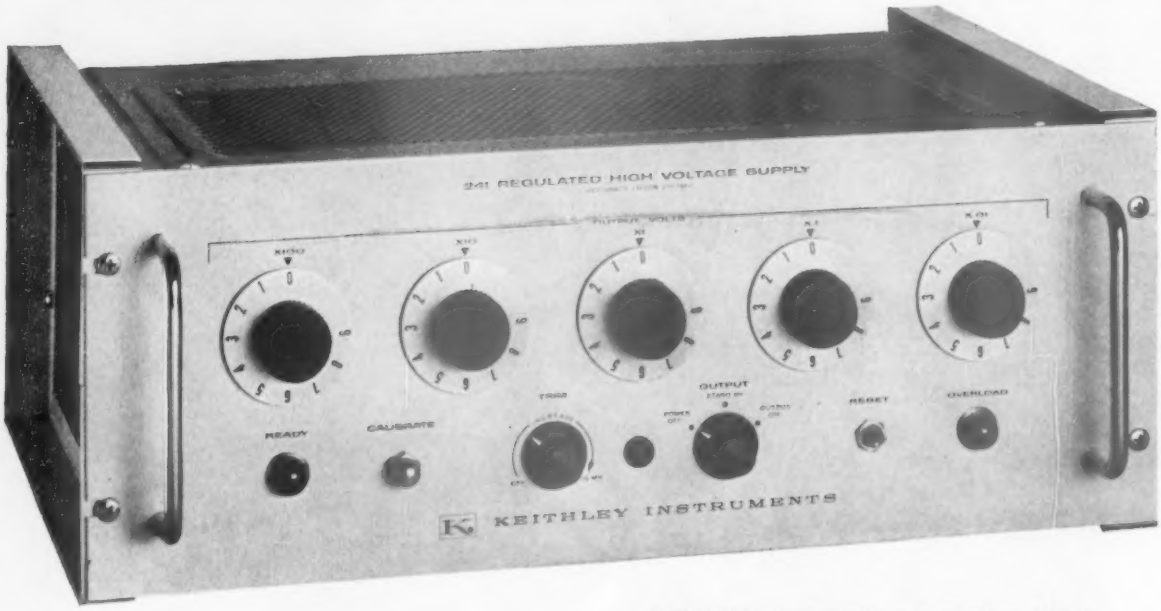
new photo-chopper-stabilized high voltage supply



Model 241 – incorporating new photo-modulator – offers high accuracy, stability, long service life. 2411 End Frames shown adapt unit to bench use.

Model 241 offers 0.05% accuracy, five-dial resolution from 0-1000 volts.

Here is the successor to dc secondary standards that employ mechanical choppers and standard cells. The new Keithley 241 offers freedom from adjustment and calibration, long term stability to voltage or temperature variations, and immunity to shock and vibration. Complementing the popular Keithley 240 supply, it offers greater accuracy, regulation, current output and floating operation.

High output accuracy, within 0.05%, is assured through the use of encapsulated wire-wound resistors with 0.02% divider accuracy.

Extreme stability of 0.005% per hour is assured by a highly stable, shockproof zenor diode, wire-wound standards in critical positions, and a highly stable, long life photo modulator which is immune to shock and vibration.

Other features include a position which removes voltage from the output, making possible connections while the instrument is operating; bench or rack operation.

BRIEF SPECIFICATIONS

Output Voltage: 0-1000 volts, plus, minus or floating. 100, 10, 1, 0.1, 0.01 volt steps; 5 calibrated panel switches. "TRIM" potentiometer permits interpolation between steps, with a resolution of better than 100 microvolts.

Output Current: Zero to 20 milliamperes.

Output Accuracy: Within 0.05% above 2 volts, within 1 millivolt below 2 volts.

Output Impedance: Less than 0.05 ohm at d.c.

Line Regulation: 0.005% or 1 mv for 10% line change.

Load Regulation: Better than 0.005%, no load to full load.

Ripple and Noise: Less than 1 millivolt RMS.

Stability: .005% per hour with constant load, line and ambient temperature.

Recovery Time: No load to full load, less than 1 second to rated accuracy.

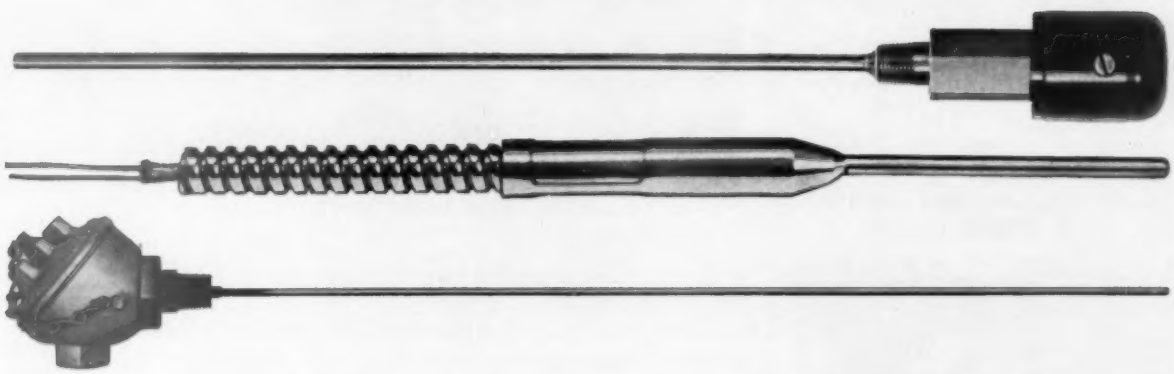
Overload Protection: Relay disconnects output within 50 milliseconds when output current exceeds about 24 ma.

Price: Model 241 ..... $775.00

For complete details, write:

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE CLEVELAND 6, OHIO

CHOOSE FROM 150,000 STANDARD *MegopaK* SMALL-DIAMETER THERMOCOUPLES



If you've been looking for small-diameter, flexible thermocouples with high speed of response, search no more. You'll find exactly what you need in Honeywell's *MegopaK** line.

MegopaK is a combination of thermocouple wires, mineral insulation and a protecting sheath, compacted into a solid mass with a diameter as small as 1/16". You can get *MegopaK* in standard lengths up to 25 feet, and in lengths up to 50 feet on special order. They're available with copper-constantan, iron-constantan and *Chromel-Alumel*** calibration. In all, there are more than 150,000 standard combinations of materials and fittings. These top-quality thermocouples are supplied in bulk, and as elements with wires welded into a measuring junction, or as complete assemblies.

MegopaK assemblies come complete with terminations (heads, plugs, etc.) and mounting attachments. Also available are special configurations, tests, material and calibration certifications.

MegopaK thermocouples and other pyrometer supplies are stocked at our Los Angeles and Dallas depots as well as in Philadelphia to give you the fastest possible service anywhere in the country.

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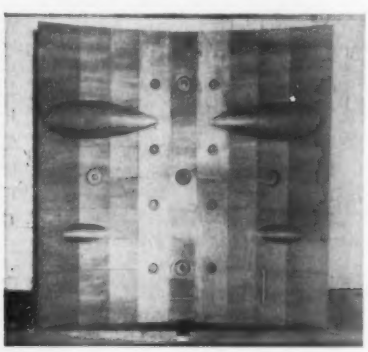

Photo shows inner wall of an 11 foot long graphite thermal column. Graphite was chosen for this installation because it is an excellent moderator of neutrons with low capture cross section.

This wall has 30 major blocks; the other 4 walls have 144 accurately machined blocks each. In all, 1300 precision machined graphite pieces are included in this thermal column. Close tolerances were held in machining each piece.

Many Universities are now using Graphite Moderated Training Reactors

Dr. E. F. Leonard, director of Laboratory Work for Columbia University, inserting a neutron source of plutonium-beryllium obtained from the Atomic Energy Commission.

A recently conducted survey shows that many universities throughout the country are using graphite exponential piles for training the sorely needed nuclear engineers of tomorrow. The survey also points out some of the advantages associated with graphite which are not found in other types of subcritical piles.

Graphite offers longer neutron diffusion (approximately 50 cm) and permits wider fuel rod spacing to assure accurate flux measurements. Also flux distortions are easily determined in graphite piles.

The structural and machineability features of graphite permit students to design and construct the pile. There are abundant experimental data and procedure history available on graphite (it's the oldest type of subcritical reactor) which permit more time for advanced experiments rather than basic fundamental experimentation.

A graphite pile also offers considerable flexibility. It is easy to change configuration, to introduce voids, to accurately position samples, and the pile can be operated as either a bare or reflected system.

Dr. T. J. Thompson, professor of Nuclear Engineering at M.I.T., removing a plutonium-beryllium neutron source from the subcritical nuclear reactor.

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*Oil not included

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General Electric Electron-Beam Generators are available in a range of models to meet production needs. Present users include W. R. Grace & Company . . . Raychem Corporation . . . Sequoia Division of Anaconda Wire & Cable . . . Suprenant Company.

You'll find General Electric Electron-Beam Generators *unequalled* for high-energy output . . . proved for their production-line reliability. Explore the potential uses within your own industry by contacting your nearby G-E x-ray office. Or write X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, Room NU-94.

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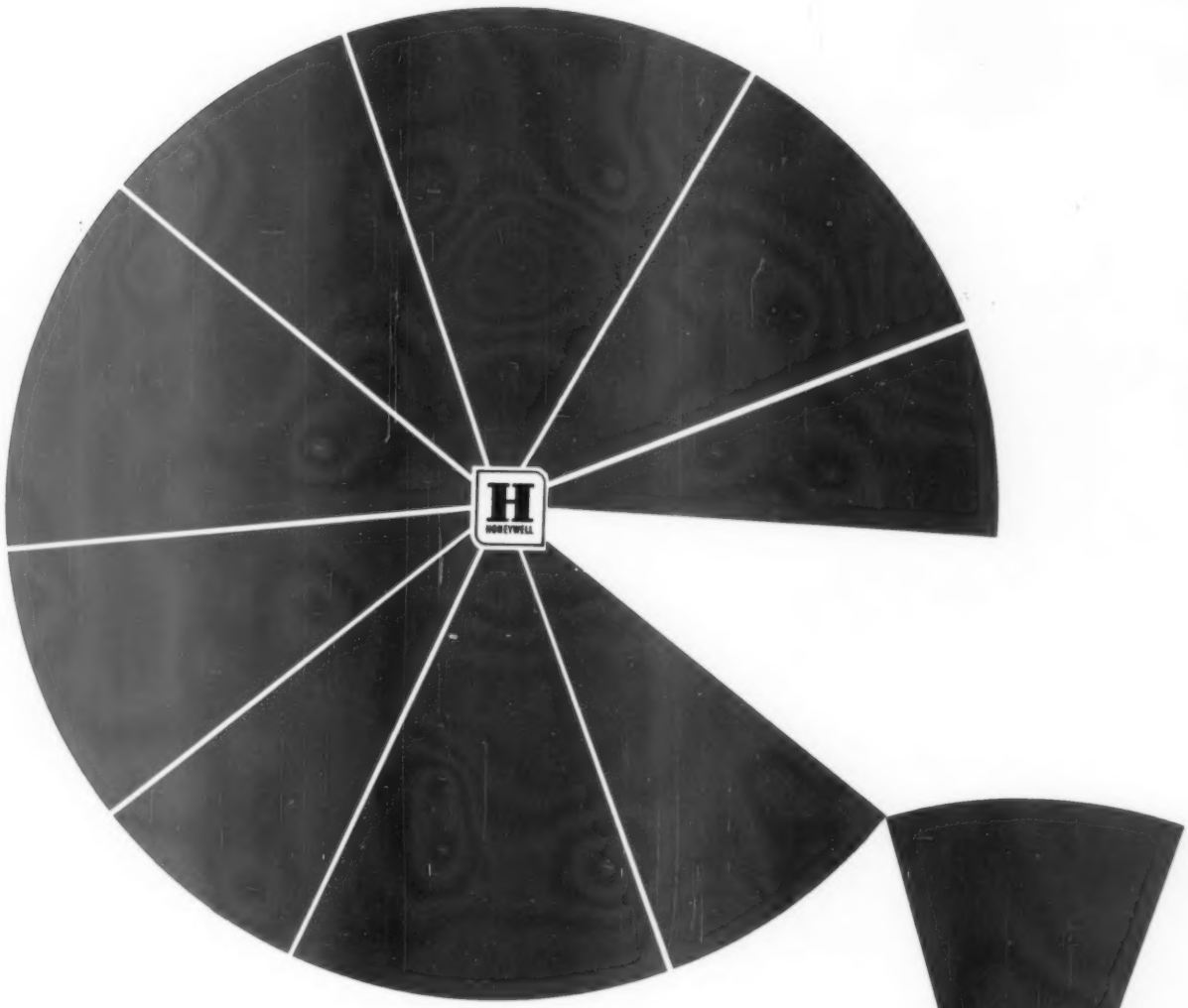

NEW HONEYWELL 290 INDUSTRIAL DIGITAL COMPUTER . . . HEART OF THE FIRST COMPLETELY INTEGRATED COMPUTER CONTROL SYSTEM

Now, with the new Honeywell 290 computer control system, you can control an industrial process or even an entire plant, fully automatically. It is the first complete control system—everything from process variable transmitter to computer to final control elements—available from any one manufacturer. Heart of the system is the new Honeywell 290 industrial digital computer.

The Honeywell 290 is the most powerful computer in its class, despite its small size, low cost and low power consumption. It performs, for example, 8,000 additions, 1,250 multiplications or 400 square root extractions per second. Unique, powerful macro-instructions help make the 290 easy to program, reduce working memory requirements and increase operating speeds. These special instructions augment the basic instructions, and eliminate many special subroutines.

The combination of high-speed operation and the reliability of conservative solid-state circuitry brings optimum control of many types of industrial processes. In addition, the Honeywell computer control system can compile complex operating guides, correlate data, and reduce huge masses of acquired data into immediately usable information for monitoring or optimizing process operations.

NEW HONEYWELL 290 INDUSTRIAL DIGITAL COMPUTER . . . HIGH SPEED, PARALLEL OPERATION, EASILY PROGRAMMED

The high computation speed of the Honeywell 290 provides many advantages in on-line monitoring and control of industrial processes:

- Higher sampling rates give closer control because each variable can be checked more frequently.
- More work can be accomplished in a given time.
- Checking and validity routines can be used extensively.
- Tasks other than process control can be accomplished either through time-sharing or through priority instructions in the computer program.

The Honeywell 290 is the first industrial digital computer to use parallel operation within the computer. All digits in a multi-digit number are transferred *simultaneously* from one element to another within the computer . . . in one count of the clock. Therefore a much slower clock rate can be used. Components are operated far below their maximum ratings—greatly increasing overall reliability, while permitting many thousands of program steps to be executed each second.

The computer combines both magnetic core and drum memory. Main memory is the magnetic core type, and it can be supplied with capacities of 1,024, 2,048 or 4,096 words. A magnetic drum memory with a capacity of either 4,096 or 8,192 words is also provided—a total capacity of 12,288 words. This combination gives you the speed and random accessibility of core memory with the program permanence of drum memory.

The Honeywell 290 Computer operates with standard, field-proved Honeywell process instrumentation in a completely integrated system of control. *ElectriK Tel-O-Set* transmitters feed process variable input data to the computer. These solid-state, two-wire transmitters convert temperature, pressure, flow and other measurements into electric signals. Various types of computer peripheral equipment are supplied by Honeywell to add flexibility to the system and make it easily expandable to meet future requirements. This equipment includes analog-to-digital and digital-to-analog converters, high-speed paper tape readers and punches, visual displays and electric typewriters. Honeywell *ElectriK Tel-O-Set* transducers make the computer completely compatible with existing pneumatic process measuring and control instruments.

Get complete details from your nearby Honeywell field engineer. Or write for Catalog C-290. MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa. In Canada, Honeywell Controls, Ltd., Toronto 17, Ontario.

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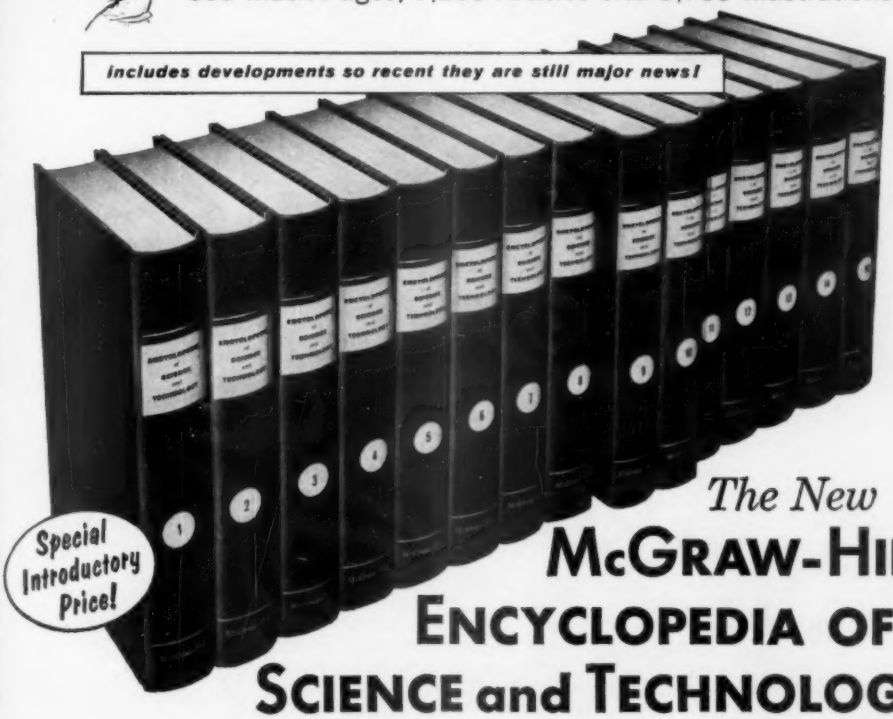

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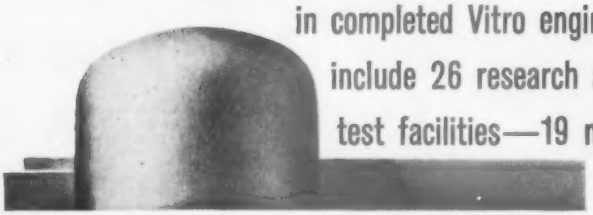
in completed Vitro engineering projects
include 26 research and
test facilities—19 nuclear...



14 which incorporate hot cells.
Both light and heavy water moderated types
are among the 21 Vitro reactor projects.
These responsibilities came to Vitro
because its technical staff
demonstrated competence and experience
to complete the whole nuclear job
from feasibility study to operation. ●

Vitro

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ALLIS-CHALMERS

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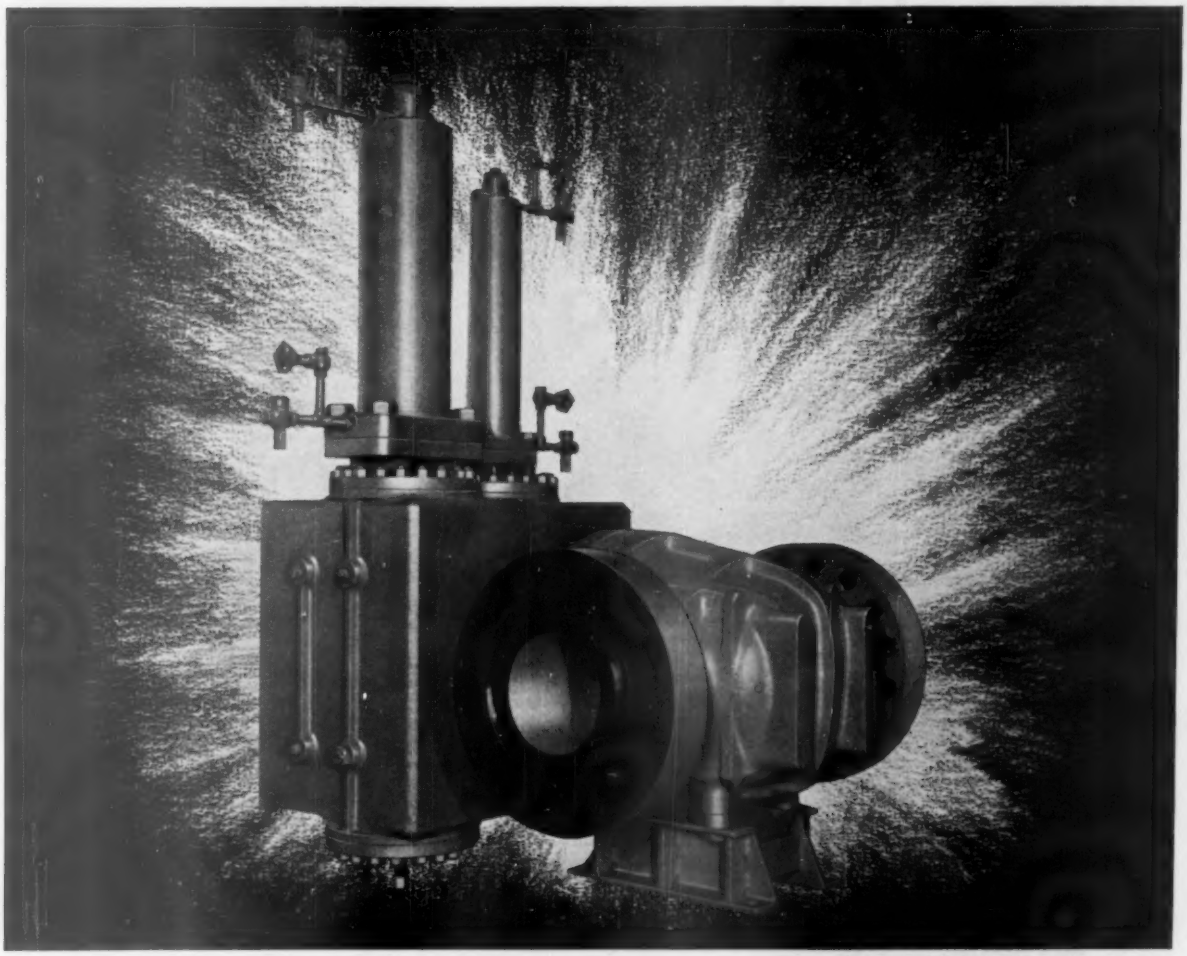


Rotovalve unit for 2700-psi, 1050 F service.

A must for nuclear reactor service . . . valves that

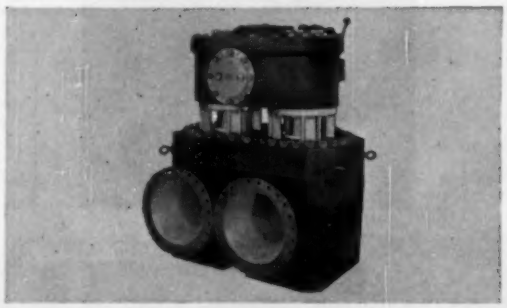
seat tighter with use

***Rotovalve* units accurately control or shut off** in high-temperature, high-pressure reactor applications. Units feature lantern ring with double packing, pressurized with the line fluid or purged to a bleed tank at lantern ring.

One example of current manufacturing is a 10-inch *Rotovalve* unit for operation at 2500 psi, 2500 F. Also being engineered is a 12-inch size for service at 4000 psi, 4000 F. Still another type combines a pair of valves within a single housing for use on dual, concentric pipes. Inner pipe carries 1400 F CO_2 to reactor; outer, 700 F CO_2 away from reactor.

Your Allis-Chalmers representative can arrange reactor valving engineered to your specific requirements. He also supplies a complete line of butterfly valves, including models for air-lock valving. *Contact him for detailed information, or write* ***Allis-Chalmers, Milwaukee 1, Wisconsin.***

Rotovalve is an Allis-Chalmers trademark.



Duplex Rotovalve unit features a single operator — controls 1200-psi, 600 F steam, or 1500-psi, 300 F air. Operator allows both valves to open simultaneously, or one to open while the other closes. Saves space vital where entire reactor unit must be enclosed in radiation-proof structure.

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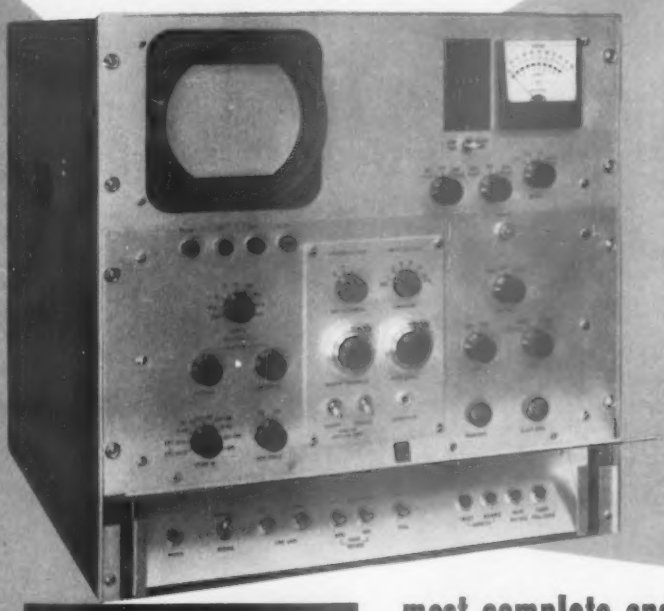

Model 34-8
200-Channel

Model 34-12
400-Channel

- automatic programming including
  - Auto-Print
  - Auto-Record
  - Auto-Transfer
- weight less than 80 pounds
- NOT microminiaturized
- ALL coincidence features
- ferrite core memory
- memory subgrouping
- 10^5 count capacity (10^6 OPT.)
- external programming
- LIVE display
- time analyzer mode
- crystal controlled live timer
- failsafe channel identification
- simultaneous print and record (OPT.)
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The Model 34-8 and the Model 34-12 are part of the NEW line of instruments designed and developed by RIDL. Whatever your instrumentation problems, RIDL has the solution. Our staff is always available to answer your inquiries. For complete information on the Model 34-8 200-Channel Analyzer or the Model 34-12 400-Channel Analyzer, write Department JTJ today.

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GAMMACELL

and

220

TWO *NEW* GAMMACELLS

TO PROMOTE

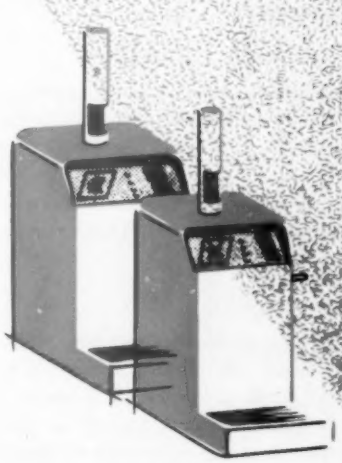
200

ADVANCES IN RADIATION EFFECTS

100

AECL announces two new Cobalt 60 Irradiators —
the GAMMACELL 100 and GAMMACELL 200

All basic features of the field-proven Gammacell 220 are retained in the GAMMACELLS 100 and 200. These two new models extend the Gammacell line to provide facilities where high fields (1,000,000 RH) in small volumes (up to 3½" diameter x 5½" height) are required.



THE GAMMACELL FAMILY FEATURES:

- **SELF-CONTAINED** — No additional shielding required. Simply set it in your laboratory and it's ready to go.
- **THREE MODELS** — with source strengths to suit any program and budget.
- **CHOICE OF DOSE RATES** — to suit your requirements — into the megarad-per-hour range and with good uniformity.
- **INHERENTLY SAFE** — by construction — radiation hazard is no problem.
- **SIMPLE TO OPERATE** — can be used efficiently by unskilled personnel; only incidental maintenance will provide years of trouble-free service.

For full details of the Gammacells 100, 200 and 220, custom irradiators, kilocurie Cobalt 60, consulting services and isotopes, please write to

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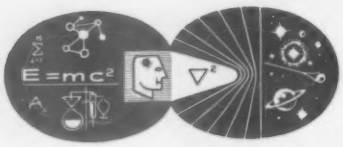
NUCLEAR SCIENTISTS and ENGINEERS

Energy Conversion  *is Our Business*

Allison Division, General Motors Corporation now is broadening its activities into *NUCLEAR* energy conversion. Presently, there are three specific programs underway:

● MILITARY COMPACT REACTOR–USAEC **● NUCLEAR ROCKET ENGINE–USAF**
● NUCLEAR DIRECT CONVERSION SYSTEMS

These new system concepts require a broadening of our nuclear capability. As a result, Allison Division has several key positions open for NUCLEAR specialists. Some of these involve project direction. If your background and experience match any of these exceptional and challenging opportunities, please contact us. We need:

● A SENIOR NUCLEAR PHYSICIST

To initiate and direct nuclear physics investigations. Will head Nuclear Physics section responsible for conducting concept feasibility and concept design studies. PhD or MS in Physics with 3-5 years experience in Nuclear Physics. Experience in reactor design and shielding analysis required.

● 2 NUCLEAR SYSTEMS ENGINEERS

To initiate and conduct Nuclear engineering studies on Compact Reactor power plants and conduct conceptual design and systems analysis of Nuclear rocket propulsion systems. MS in Nuclear Engineering or MS in Mechanical Engineering with considerable advance courses (ORSORT) in Nuclear technology. At least 5 years experience in Nuclear field, preferably in propulsion area.

● 3 NUCLEAR PHYSICISTS

To conduct Nuclear physics studies on Nuclear Rocket Engine, Military Compact Reactor and Nuclear Fuel Cell Programs. Will perform reactor physics design calculations and shielding studies for high temperature reactor systems. MS in Physics with minimum of 5 years experience in Nuclear field. At least 2 years experience required in systems analysis and preliminary design of Nuclear systems. Experience required in use of IBM 704 type computer.

● 2 REACTOR KINETICS ENGINEERS

To initiate and conduct reactor and power plant control and instrumentation studies and design for Military Compact Reactors. MS in Nuclear Engineering (or ORSORT graduate) with 2-5 years experience in Nuclear instrumentation and control. Experience required in Reactor Kinetics design, preferably in high temperature reactors.

● 4 REACTOR ENGINEERS

To conduct systems analysis and evaluation for Military Compact Reactor project. Will perform parametric analyses and system criteria comparisons. Graduate of ORSORT, or MS in Nuclear Engineering with 2-5 years experience. Minimum 2 years experience in reactor design and power plant systems evaluation.

Send your resume today to the attention of Mr. V. A. Rhodes, Dept. 8310 Scientific Personnel Recruitment

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General Motors Corporation
Box 894, Indianapolis 6, Indiana

GM GENERAL MOTORS

RADIATION AREA

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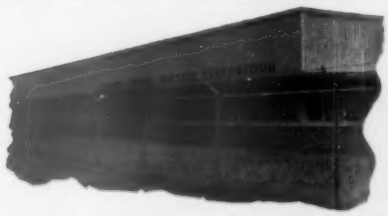
VICTOREEN AREA MONITOR

Photographs courtesy Sylvania-Corning Nuclear Corp.

Victoreen Leads in Monitoring with over 1000 Channels in the Field and Operating



SYLCOR Plant, Hicksville, Long Island, New York, is equipped with the latest Victoreen multichannel area monitor. Centrally located control panel, with visible and audible alarms, is connected to sensing elements throughout plant for maximum radiation protection.

Perfected. The monitoring systems Victoreen is delivering today incorporate the design refinements made from experience with over 1000 channels in field use under every conceivable type of ambient condition, including indoor and outdoor use and even under water.

Proven. Victoreen monitoring systems have proven themselves — where proof counts most — in the field and in regular operation under the most adverse conditions.

Preferred. With far more channels installed and successfully operating than any other manufacturer, the preference for Victoreen monitoring is unassailable. And Victoreen continues to increase its lead in monitoring leadership. A-2779A

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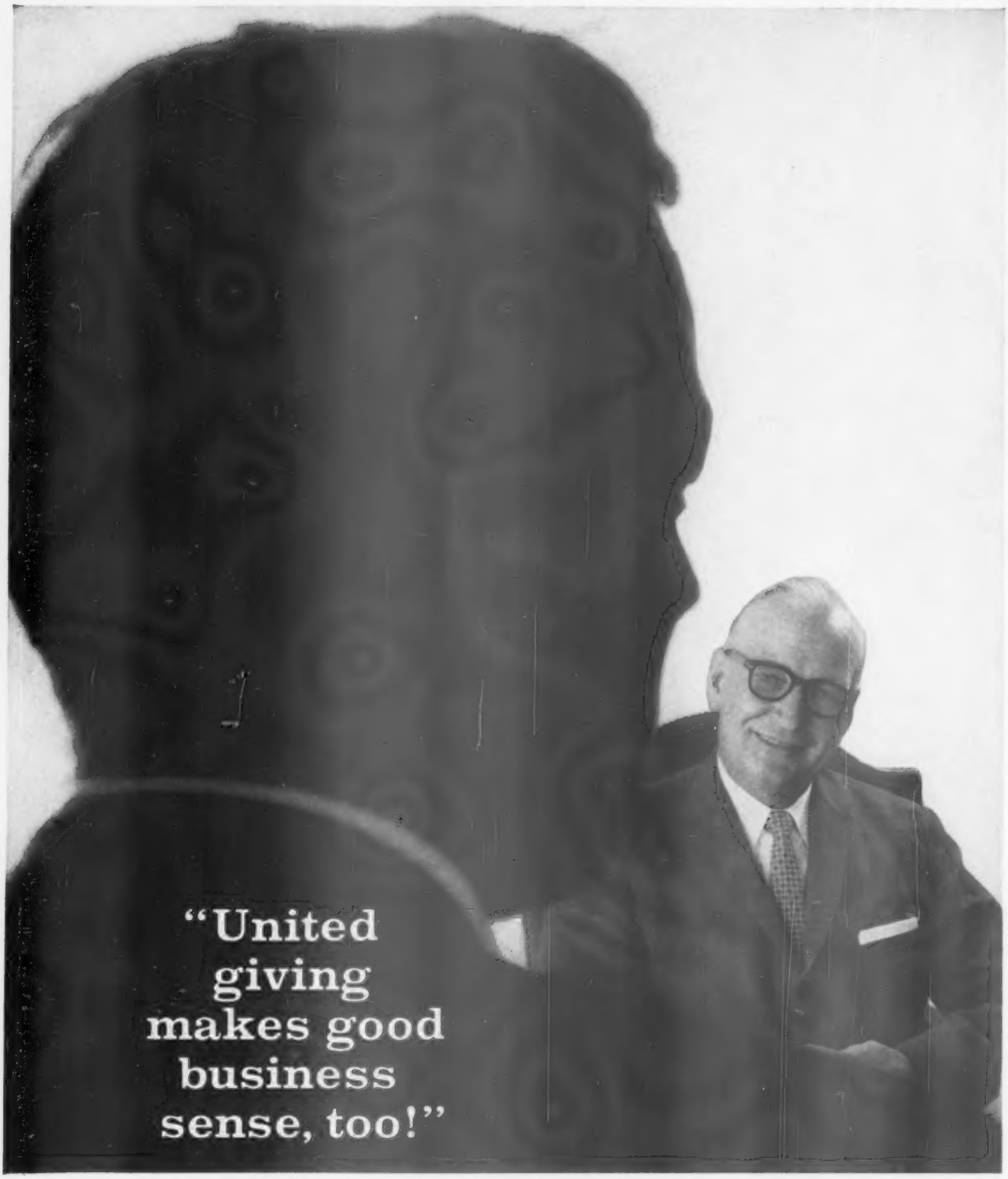
WORLD'S FIRST NUCLEAR COMPANY



Every business has a vital stake in the welfare of its community. The businesslike way to protect these interests is to support your community The United Way. Your United Fund or Community Chest Campaign takes care of many community needs without the confusion and waste of separate appeals.

Your company can contribute in *three* important ways! ■ Make sure your company makes a generous corporate contribution. It helps protect the welfare of your employees and customers. ■ Help your employees meet their obligations through easy payroll payments. Experience shows this often doubles, even triples, results. ■ Stimulate executive participation in support of your local fund. Such participation helps safeguard the dollar investment made by your company and its employees.

Remember, giving The United Way helps your community *and* your company. **GIVE THE UNITED WAY**

Zero leakage nuclear pumps

Four BJ Liner-Motor Pumps Provide Primary Cooling for AEC's SPERT-III Project

High temperature, high pressure and high capacity performance *with zero leakage* are demanded of these four Byron Jackson Liner-Motor Pumps. Employed to handle pressurized water for primary coolant at the Atomic Energy Commission's SPERT-III project near Idaho Falls, the 500 HP pumps are operating at 650° F, 2500 psig, and are rated at 5000 GPM with a total dynamic head of 350 feet.

In building pumps to such critical requirements, BJ calls upon the engineering skills and manufacturing methods that have made Byron Jackson a leader in nuclear pumps for all types of reactors...stationary, or portable. The success of BJ nuclear pump design is proved through the installation or specification of BJ Pumps on practically every major commercial reactor in the United States.

BJ quality *does* cost less in the long run!

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Byron Jackson Pumps, Inc.

A Subsidiary of Borg-Warner Corporation

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Wah Chang Corporation produces and supplies pure Columbium and Columbium base alloys in the form of vacuum electron beam ingots, vacuum arc melted ingots, vacuum sintered ingots, tubing, sheet, rod, foil and powder and fabricated parts.

Columbium ingots up to 16″ diameter weighing up to 5,000 lbs. are available.

Pure Columbium's extremely high melting point of 4379°F is solving incredible temperature problems encountered in hypersonic travel, as well as for nuclear, jet and rocket powered-aircraft.

WCC is also a major producer of Hafnium control rods.

For technical information, write outlining your requirements.

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BRINGING TOMORROW CLOSER WITH NEW METALS

Leading Producers and Fabricators of:

Hf	Zr	Ta	Mo	W
HAFNIUM	ZIRCONIUM	TANTALUM	MOLYBDENUM	TUNGSTEN

JET ENGINE TURBINE WHEEL MADE OF A-286 MATERIAL WEIGHING ABOUT 13 POUNDS—FILLS ONE OF TODAY'S MOST DEMANDING APPLICATIONS FOR A PRECISION MEMBER.

13,000 POUND THROTTLE VALVE BODY MADE OF CHROME MOLY MATERIAL FOR HIGH TEMPERATURE, HIGH PRESSURE APPLICATION.

EXTREME SERVICE COMPONENTS FOR JET ENGINES, GUIDED MISSILES AND NUCLEAR POWER PLANTS

REFRACTORY MATERIALS FOR SERVICE TEMPERATURES TO 5000° F—EXOTIC METALS AND MANY OTHERS.

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Cameron forgings are not like other forgings. In the tradition-bound world of metal working they possess new properties, better quality and unusual shapes. They have opened new design vistas when high stress, high temperature or large intricate components were a concern. In less demanding applications also, benefits have made their appearance in the form of easier machining, less fabrication and geater strength, resulting in less material and lighter weight.

Cameron forging technique requires a complete operation from molten steel to final inspection. Presses, furnaces and auxiliary equipment of our own design give complete quality control and independence in production schedules.

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10" Stainless Steel cylinder-operated, 150 lb. gate valve equipped with special limit switches.

For control of demineralized water

...Darling developed this special nuclear valve. It is but one of several types Darling is producing for nuclear applications.

The combination of advantages Darling offers you includes:

- **Flexible thinking**
- **Rigid quality control**
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Why not employ our specialized experience, closely-integrated facilities and outstanding quality reputation on *your* nuclear valve requirements?

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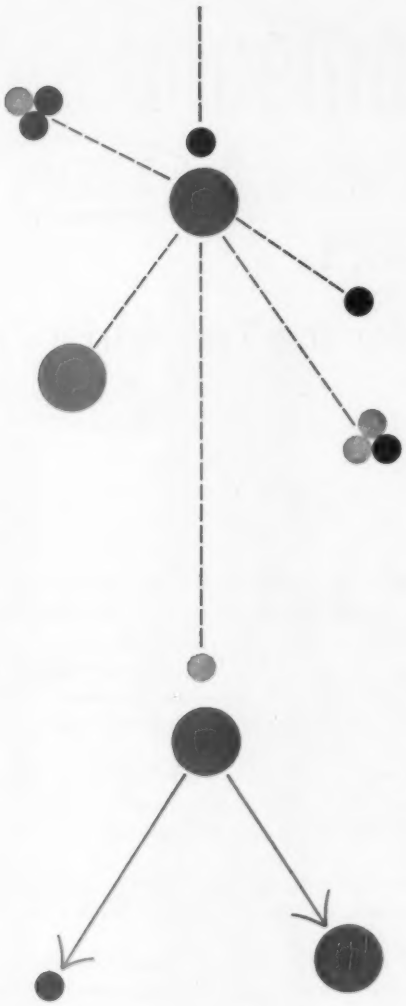

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GUARANTEED PULSE-HEIGHT RESOLUTION UNDER 9%

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RCA-7746 is capable of an essentially linear current amplification of 16,000,000 when operated at a supply voltage of 2,000 volts. Spectral response covers the range from about 3,000 to 6,500 angstroms, with maximum response in the blue region at approximately 4,400 angstroms.

For further information on RCA-7746, or any of RCA's broad line of high quality multiplier phototubes, get in touch with the RCA field office nearest you. If you would like a technical bulletin on RCA-7746, write RCA Commercial Engineering, Section I-31-Q, Harrison, N. J.

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The Case for the Terrestrial Traveler

Figure that every thirteen seconds American drivers motor 238,000 miles – the distance to the moon. Increasing the efficiency, comfort, and safety of this incredible private transportation system (60 million cars!) is a top project goal of the General Motors Research Laboratories. From this sizable R & D program have already come a number of experimental controls and driver aids now being evaluated in the field.

New ways of supplying drivers with traffic and road information – electronic edge-of-road detectors; communication systems for giving drivers audible road and emergency information.

Simplified driver controls – Unicontrol, a servo system in which the driver steers, accelerates, and brakes his car with a single control stick.

Tested methods of automatic vehicle control – refined computers and electro-hydraulic servomechanisms that automatically guide cars and control their speed and spacing.

Underlying these developments are a continuing series of fundamental studies. In vehicle dynamics research: investigations of the effect of tire properties, suspension geometry, mass distribution, springs and dampers on the ride and handling characteristics of cars. In human factors research: experiments to determine the perception and response of drivers to various traffic situations using different car control systems.

At GM Research, we believe such fresh approaches will improve car-driver compatibility, providing additional convenience and enjoyment for tomorrow's terrestrial traveler.

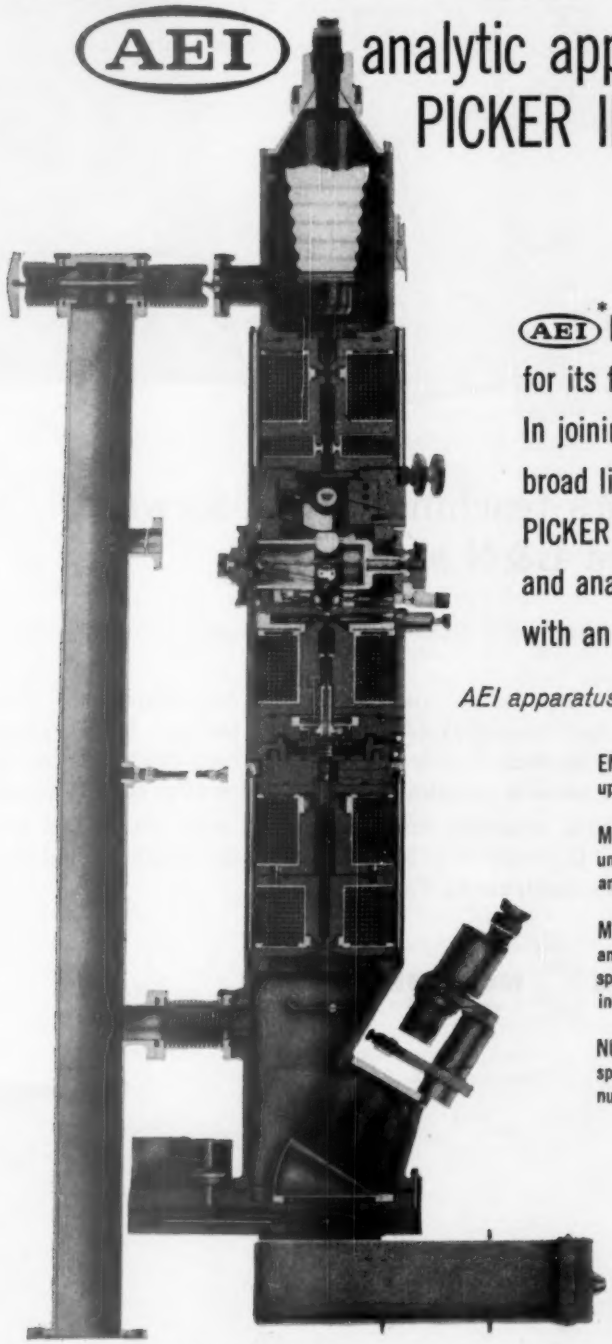
General Motors Research Laboratories

Warren, Michigan

Car pickup coils and road wiring used for guidance and speed control in one experimental automatic highway system under study.

announcement

AEI analytic apparatus now distributed by PICKER IN U.S.A. and Canada



AEI* laboratory instrumentation enjoys world reknown for its forward concepts and precision craftsmanship. In joining this fine British-made apparatus to its own broad line of x-ray diffraction and nuclear instruments, PICKER is now in a unique position to serve research and analytic laboratories in this country and Canada with an apparatus line of extraordinary embrace.

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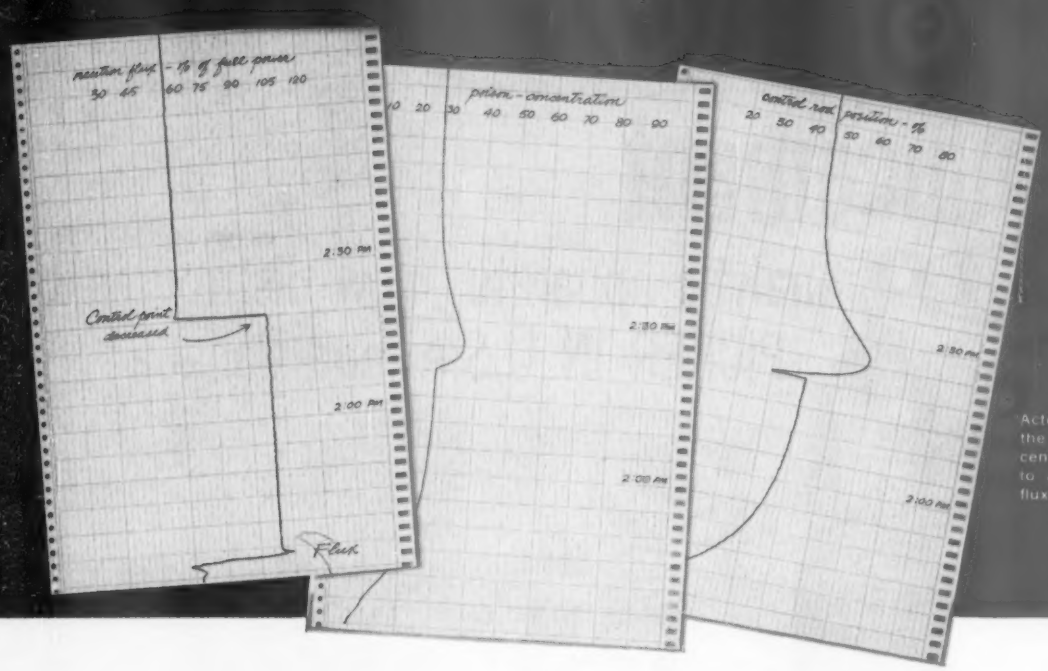
FOR DETAILS / call any Picker office of the nationwide Picker Sales/Service organization. (See local 'phone book) or write PICKER X-RAY CORPORATION, 25 South Broadway, White Plains, N.Y.

if it has to do with RADIATION / it has to do with Picker x-ray



Actual chart records show the response of poison concentration and control rod to a decrease in neutron flux control set point.

NOW... Reactor kinetics teaching moves forward with advanced L&N simulator

Using advanced components and circuitry, the latest L&N Nuclear Reactor Simulator vividly demonstrates the dynamics of reactor kinetics.

Two integrated analog computer circuits perform all calculations for this educational tool. One circuit simulates the time variations of neutron flux. The other adds reactivity feedback from average reactor temperature and poison concentration. With such flexible circuitry, a variety of studies can be made of neutron flux and reactor coolant systems dynamics—duplicating the operation of an actual reactor.

Before planning your nuclear reactor training program, may we suggest that you contact our Nuclear Systems Group. Its members will be glad to supply more information on this flexible Simulator. Write Leeds & Northrup Co., 4936 Stenton Ave., Philadelphia 44, Pa.

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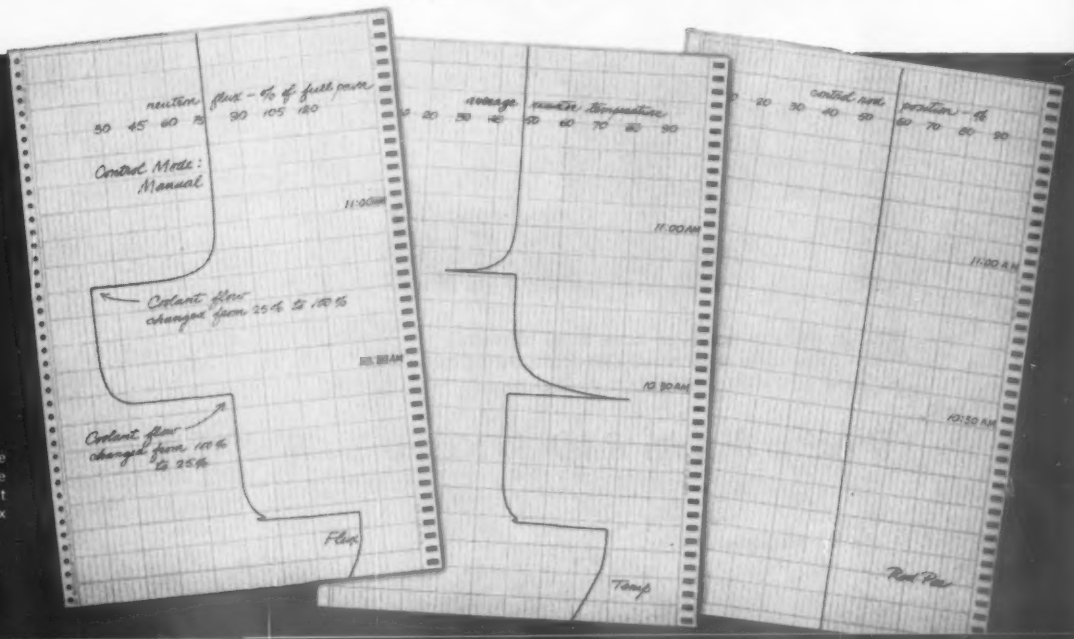
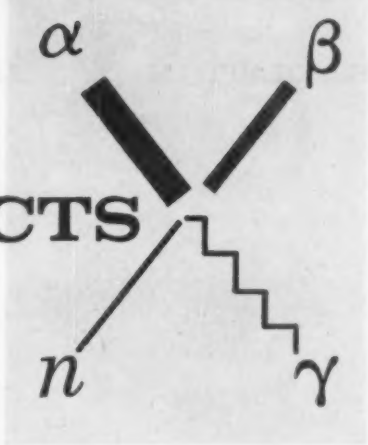


These records show the stabilizing effects of the average reactor coolant temperature on neutron flux with manual control.

ADVANCES IN
RADIATION EFFECTS



A Nucleonics Special Report:

Designers, builders and operators of reactors and radiation-processing equipment need to know how radiation affects the materials they use. Efforts at learning the answers are progressing from screening tests toward careful experiments that more nearly duplicate actual conditions in advanced nuclear hardware. This NUCLEONICS report evaluates the body of knowledge that has emerged from all the data and theory accumulated on radiation effects.

Where do we stand? We are acquiring a better understanding of the behavior of organics and metals. There is the whole new field of pulsed-radiation effects—this subject, which presently gets most of its push from military concern with the effects of strong radiation pulses on electronic devices, is proving to be of great importance to those interested in the mechanisms of radiation effects. The effects of radiation combined with other environments is another area where experiments are replacing empirical relationships. All this makes for the deeper understanding that will build a solid foundation of materials technology for hotter nuclear equipment.

Where do we go from here? From this look at the status of radiation-effects technology it is clear that higher-temperature irradiations are needed, as are better means of measuring fast fluxes. No less important are better methods and equipment for testing components under actual conditions to be encountered in new reactors. Along with the knowledge from better experiments will come a more complete theory, though we are still far from the kind of complete theory that would explain radiation effects in practical systems from first principles.

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RADIATION EFFECTS

Relaxing Reliance

The need for understanding creep, fatigue strength and the behavior of refractory metals grows as reactors go to higher temperatures and fluxes. Experimenters need to base tests on the newest solid-state theories to get significant data

By DOUGLAS S. BILLINGTON, *Solid State Division, Oak Ridge National Laboratory,* Oak Ridge, Tennessee*

DESIGNERS OF REACTORS built to date have relied on empirical data on radiation-induced changes to materials. Generally this has been suitable. But questions arise concerning points such as fast-neutron effects on precipitation-hardened alloys and the brittle fracture of carbon steels, as well as gas formation and swelling in some metals when exposed to thermal neutrons. In trying to understand and solve these problems we see that today's empirical data are couched in terms that are antiquated and inadequate to the task of building improved reactors. Although experiment methods have improved and help evolve a true and unified understanding of material behavior, far too many gaps remain in our understanding. This article comments on recent advances in reactor materials and points out typical gaps that need filling soon.

Theoretical vs. Actual Damage

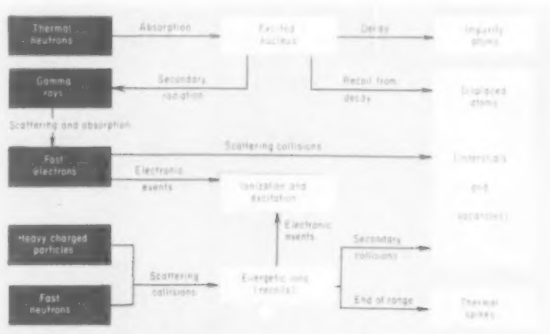
The theory of radiation damage helps us to understand and predict property changes in a qualitative way. Still, strictly theoretical calculations of radiation damage to a material turn out to be up to ten times higher than the change that actually occurs. One explanation of this discrepancy is that vacancies and interstitials recombine more extensively than present theory predicts. Another reason probably is that measurements of dose rate and spectrum are not as accurate as is needed, particularly for the fast neutrons that cause damage by displacement. Small changes in the flux spectrum can cause widely different types and amounts of radiation damage over a period of time.

Because of such uncertainties, it is apparent that irradiation test conditions must approximate the planned service conditions as closely as possible. In the meantime, efforts continue toward improving radiation dosimetry and the understanding of recombination reactions.

Cryogenic irradiations. To get a truer measure of the number of defects formed in a metal, radiation-effects experiments at extremely low temperatures are being made. Since most defects formed by irradiation should be immobile at low temperatures, the dislocated atoms and vacancies should be less likely to recombine. Many related experiments have employed fast charged particles (*1–3*), but reactor irradiations, which are more directly relevant to reactor problems, have involved various metals and alloys at temperatures of 4° K or lower (*4–6*). As expected, damage rates as measured by electrical conductivity are appreciably higher at these low temperatures, but the rates still are not high enough to show agreement with theory. Defects move in copper as cold as 7° K. On the other hand, copper's mechanical properties (hardness, tensile strength, etc.) seem relatively insensitive to the irradiation temperature below room temperature, both as regards the rate of strength increase and the fact that no annealing occurs. Thus, the causes of resistivity change are not the same (or are not the same size) as the causes of strength changes.

Thermal Neutrons Cause Transmutation

Even minor impurities can markedly change the properties of reactor structural metals and alloys when they are exposed to thermal neutrons and transmuted. We become concerned about gas-producing reactions in reactor components because they can lead to swelling and gross distortion in ductile materials or can lead to stress-inducing points that lead to embrittlement and fracture



NATURE OF RADIATION-DAMAGE processes points to qualitative understanding of changes in material properties. Most changes to metals are caused by fast neutrons that produce vacancies and interstitials. Heavy fission fragments cause transient thermal spikes and then act as impurities. Thermal neutrons also transmute atoms to form impurities. But empirical knowledge must give way to quantitative understanding as the need grows to extrapolate test data to future reactors

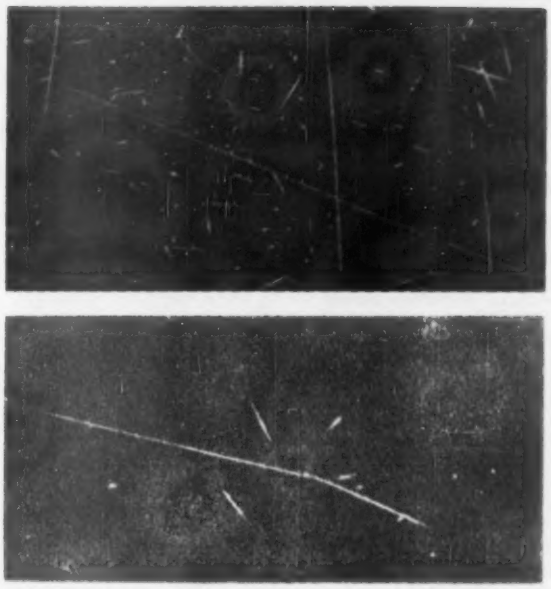
* Operated by Union Carbide Corp. for the U. S. Atomic Energy Commission.

on Empirical Data

Actually Seeing Lattice Changes Aids Understanding

Now that we can detect dislocations and see them move and interact with one another, we have progressed surprisingly in understanding how radiation-produced defects change a solid's properties. Most of this progress has come about through transmission electron microscopy of thin films (15, 16). Also, by making dislocations in transparent solids visible we can observe interactions microscopically (17–19). Recent advances in X-ray techniques prove greatly valuable in identifying defects in solids and in following interactions of defects (20, 21). Fission-fragment tracks have been observed in thin mica sheets (22) as well as in UO_2 films.

Such methods help us to tell whether radiation-induced defects affect properties of a solid by direct interaction with the crystal lattice or by interaction with lattice defects already present [examples: many dislocations always exist in cold-worked metals; numerous impurity (alloying or contamination) atoms are in most solids; copious lattice vacancies usually occur in material that has been quickly cooled from high temperatures]. Still, a quantitative relationship between the number and kind of defects and the value of a specific property has not been established, except partially in a few cases. But the new "tools" becoming available help put us on the track to the deeper comprehension of material behavior that can relieve our dependence on empirical data alone.



FISSION-FRAGMENT TRACKS IN UO_2 are made visible by transmission electron microscopy methods. At top, fragments traveling in plane of 100-Å film of UO_2 made long tracks; fragments ejected out of film made very short tracks and dots (25,000×). Below, bend in track shows where fission fragment collided with oxygen atom in UO_2 lattice (50,000×)

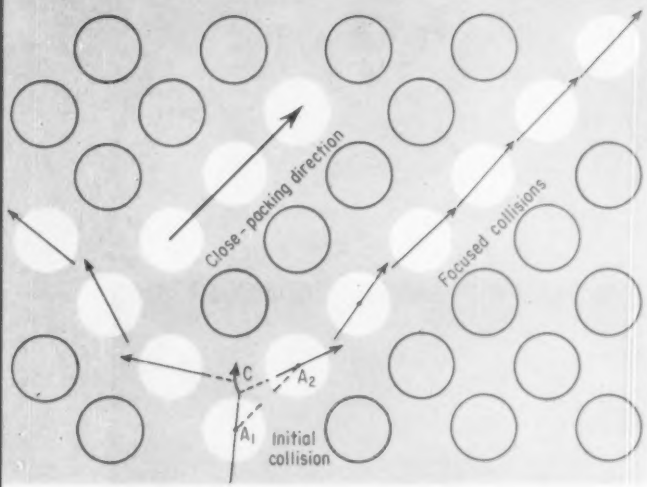
of both brittle and ductile materials. For instance, tests involving burst tests of thin-walled tubing show that the in-pile life of a metal such as Inconel is shorter (often by a factor of two) than that of an unirradiated tube (*7, 8*). This change is attributed to transmutation of B^{10} in the trace boron in the Inconel to form Li^7 and He^4. In time enough helium collects at the grain boundaries to weaken the tube. Careful experiments are underway to learn quantitatively how boron content changes in-pile life.

These tube-burst tests emphasize the importance of specifying reactor components by composition and not only on a performance basis as is customary in other fields.

Gas formation in Be, Mg. Gas-producing reactions take place under irradiation, not only in impurities such as lithium and boron, but also in some important reactor structural materials such as beryllium and magnesium (*9*). For example, the (n,α) reaction in Be^9 produces $2He^4 + H^3$; the threshold energy is 0.7 Mev. The reaction Be^9 $(n, 2n)2He^4$, threshold energy 1.84 Mev, has an even larger cross section. The reaction $Mg^{25}(n,\alpha)Ne^{22}$ also takes place, though the cross section is only 0.006 barns.

The gas-producing transmutations in beryllium do not cause serious swelling at low temperatures. But when beryllium is to be used above 550° F there might be an appreciable volume change. Experiments to learn volume change should involve irradiation at the elevated temperature of interest—it is not sufficient to irradiate at low temperature and then heat-treat at the proposed operating temperature. These two experiments are not necessarily equivalent and might give different answers because irradiating at 550° F probably is equivalent to heat-treating *above* 550° F after irradiation. Furthermore, since the concentration of vacancies and interstitials becomes high because of storage during the low-temperature irradiation, the total recombination might be greater and thus the total increase in diffusion might be less than when irradiation is at high temperatures. The type of effect should be similar in both cases but often will differ in extent of change. In any event, irradiation at the proposed operating temperature should give the most reliable answer.

Swelling of control rods, fuel. The gas-formation problem is not serious in most reactor components at neutron flux levels in present-day reactors, except in uranium and plutonium fuels and in boron where it is a control-rod constituent. Even in these components the problem is not important where the temperature is only 200–400° F, because at low temperatures the gas atoms remain locked in the lattice and do not agglomerate to form gas bubbles. The nuclear reaction that produces the most gas is the fission reaction in uranium and plutonium. Xenon and krypton are produced in appreciable quantity



FACT THAT KNOCKED-ON ATOMS CAN FOCUS along close-packed lines of atoms (23–26) helps explain unexpectedly long range of many displaced atoms as revealed by experiments involving dislocation pinning during low-temperature irradiation (27). Other experiments excellently measure range of struck-on atoms (28). Thus, new data should give heavy boost towards better quantitative view of radiation effects

(12–15%) and thereby create a problem that is common to all solid fuel elements particularly at high temperature.

It is important to keep the gas atomically dispersed because the lattice forces keep the atoms locked in position, whereas in the agglomerated state the restraining force is the yield strength, which in the usual material is a factor of ten lower. Agglomeration of the gas atoms into bubbles probably depends on vacancy diffusion (*9*); at low temperature low mobility prevents diffusion.

Since the most likely source of vacancies is the grain boundaries of the material, specification of large grain size should help reduce the available supply of vacancies even though irradiation itself causes new vacancies.

Precipitation-Hardened Alloys

Fast-neutron irradiation accelerates solid-state reactions. Neutron irradiation speeds vacancy-diffusion reactions because it adds vacancies above the equilibrium number; thus diffusion takes place more quickly at a given temperature. This bears importantly on many materials that are considered for reactor applications—many industrially important alloy properties (obtained by careful choice of time and temperature treatments) are well chosen for use in the absence of radiation, but they might be unsatisfactory in a radiation field.

For instance, the widely used precipitation-hardening alloys usually depend on diffusion to attain suitable properties. Irradiation of several alloys accelerates the precipitation process and makes the material behave as though it were 100–300° F hotter than it actually is (*10–13*). These alloys are always in a metastable state and the net result is to enable the material more nearly to approach equilibrium. Thus the material's temperature stability apparently becomes lower than in the absence of radiation.

Although irradiation promotes diffusion, there is no effect if the irradiation temperature is so low that the defects have no mobility. But the excess vacancies that are frozen in at low temperature can be released subsequently by heating the metal and thereby speeding up diffusion. On the other hand, if the temperature is high enough the number of thermally generated vacancies is so large that the number introduced by radiation becomes trivial and so will not have an observable effect on the speed of diffusion.

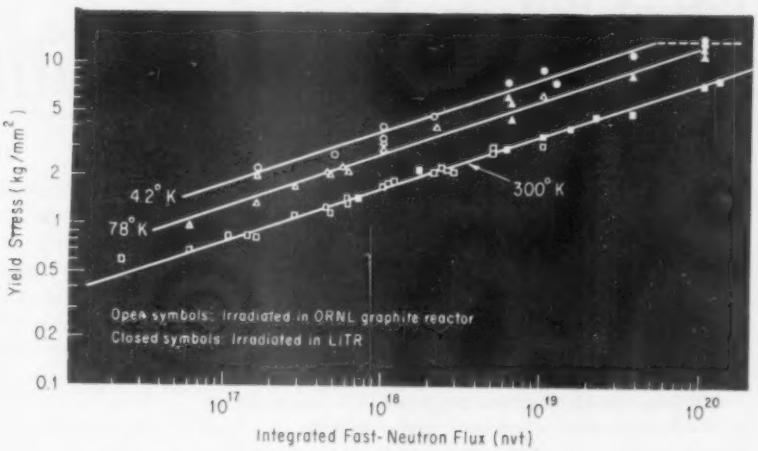
Brittle Fracture of Pressure Vessels

Characteristic brittleness of low-carbon ferritic steels at low temperature (even in the absence of radiation) always has seriously concerned builders of pressure vessels. Under irradiation these steels not only become more brittle, but the temperature at which they remain brittle increases appreciably. The ductility loss is viewed with misgiving because it might lead to failure if reactor thermal gradients introduce high stresses. Thus, to insure ductile behavior the operating temperature must be raised.

For some reactor designs this is unimportant because the operating temperature is high enough. However, merely increasing the temperature may not be the answer for certain types of steels. For example, increasing the irradiation temperature does dampen the radiation-induced yield strength increase, but it actually might increase the tensile strength with no increase in ductility (*7*). The explanation is not immediately apparent; it might be caused by small changes in chemical composition, quenching temperature and cooling rates, or other variables such as grain size—or previously undetectable reactions might be taking place because of irradiation-enchanced diffusion rates. Thus a suitable theory of brittle fracture in the presence of radiation does not appear imminent and generally we still must rely on empirical data for answers to design problems.

Boiler codes not applicable. The increase in ductile-brittle transition temperature and loss in impact strength of pressure-vessel steels still needs study. But it is well established that after irradiation the interrelationship of various properties, such as hardness, yield strength and ductility, is not the same as in the unirradiated state. Thus, present boiler codes do not apply for irradiated metals. Solution of this problem is particularly knotty because it is not desirable to deliberately cause failure through in-service or simulated in-service tests in the presence of radiation. Thus, the matter of using full-size components of conventional materials under unusual conditions, without being able to test full-sized components under service conditions, involves vast difficulty and is challenging in the extreme.

Surveillance samples. The inability to predict confidently how critical reactor components will behave after long-time irradiation has led to the expedient of placing a large number of surveillance samples in the reactor in positions where the neutron flux level is slightly higher than that of the component. These samples are fabricated at the same time as the reactor component and have the identical composition and fabrication history. Periodically, samples are removed and impact, tensile and other measurements are made. Thus, drastic changes in the behavior of the reactor component can be anticipated. And then, if needed, appropriate heat treatment can be applied to the reactor component or operating temperature can be altered to alleviate the situation. An appropriate nondestructive test that could be applied to either sur-



YIELD STRESS INCREASE induced by irradiation of copper varies as cube root of fast-neutron dose, while most theories indicate a square-root dependence. Lack of suitable explanation seems chief hurdle to understanding mechanism of radiation-induced hardening of metals

veillance samples or the reactor component itself would be most welcome.

Advanced Reactors = New Problems

Creep. Several years ago we learned that radiation decreases the creep rate of a number of materials. So, generally, study of creep was dropped. But since these earlier creep experiments involved such low temperatures and fluxes that only the hardening effect of radiation was observed, interest in advanced reactors suggests that the problem should be re-examined—particularly if vacancy concentration is thought important in creep at high temperature. If a metal or alloy creeps by a dislocation climb mechanism, then higher fluxes mean higher vacancy concentrations and higher temperatures mean greater mobility of the vacancies. Both these factors could lead to a change at fluxes of 10^{15} or 10^{16} nv. In the absence of recombination we might expect a doubling in creep rates of copper under irradiation at 10^{13} nv, even at room temperature (*14*). Still, with 90% recombination of vacancies and interstitials, which seems more reasonable, 10^{15} nv might appear to be a critical flux if the temperature is high enough.

There are two ways to look at the creep problem: (a) creep rates might be increased by enhanced diffusion rates that either accelerate dislocation climb or increase diffusion rates of solid-state reactions that normally do not take place at the temperature under consideration; (b) the ductility loss might shorten the steady-state creep stage seriously—that is, the material might creep in a conventional fashion but fracture at lower total elongation. This latter type of failure could be extremely serious, since detection before failure would be difficult.

Fatigue strength. I am not aware of any in-pile experiments having been performed to learn how neutrons affect fatigue strength of metals or alloys. But the design of complex high-performance reactors raises increasing concern about the possibility of fatigue failures. This concern comes about because of the lack of understanding of the role of vacancies in fatigue failure even in the absence of radiation, although it is believed that the role of vacancies could be important. For example, the alternating stresses applied in an operating reactor might cause interacting dislocations to generate vacancies, which in turn agglomerate to form small voids causing a small region of weakness that then initiates a crack leading to fracture. Fatigue tests as a function of irradiation temperature and neutron flux appear needed.

Refractory metals. Because they have very high melting points, the body-centered cubic refractory metals—such as tungsten, molybdenum, tantalum and niobium—hold promise and merit appropriate tests.

Conclusion

The revolution taking place in our understanding of the nature of solids, partly brought about by radiation studies, forces us to re-examine all our old concepts about the behavior of solids. We believe that we have the experimental tools and the basic theoretical framework with which to predict the behavior of solids, and we need no longer rely on empirical knowledge alone. However, complete conversion of this basic understanding into information for reactor design will not come immediately—there are too many different types of solids and too many details, both theoretical and experimental, that must be filled in first.

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Radiation Effects

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As temperatures, pressures, stresses, lifetimes and radiation intensities of interest for reactor design rise, so too does the need for realistic data on radiation effects on metal structures under these conditions.

Design of higher-performance reactors relies on assurances that suitable materials are available. Although recent tests generally substantiate earlier findings (*1*) about radiation effects on reactor metals they also uncover vital questions concerning extrapolation of limited test results to actual complex reactor environments. In addition to a straightforward need for more comprehensive data on material exposed to higher neutron doses and temperatures, we need to be able to measure and calculate the effectiveness of various fast-neutron spectra—which probably must await experiments with the Dounreay, EBR-2 and Enrico Fermi fast-breeder reactors.

Radiation-induced changes to metal core structures and vessels are known to be affected by material purity, grain size, temperature, stresses and their cycles; current work points toward tightly defining the importance of each of these variables. These studies are rounded out by attention focused on finding the causes of pitting, swelling, cracking and embrittlement of zirconium and other promising cladding and control materials.

TABLE 1—Changes in Tensile Properties of Alloy Steels*

Dose (*nvt*; > 1 *Mev*)	*Yield strength* (10^3 *psi*)	*Ultimate strength* (10^3 *psi*)	*Total elong.* (%)	*Uniform elong.* (%)
8.5% Ni				
0	91.8	119	29.5	21.5
1.7×10^{19}	138	148	18	11
1×10^{20}	183	184	5.5	2
Carilloy T-1				
0	120	129	14	8
1.7×10^{19}	170	171	4.5	0.5
1×10^{20}	186	187	3.7	0.3

* Strain rate = 0.5 in./min; irradiation temperature = 205° F.

TABLE 2—Changes in Tensile Properties of 3 Fine-Grain Steels with Different Carbon Contents

Dose (*nvt*; > 1 *Mev*)	*Yield strength* (10^3 *psi*)	*Ultimate strength* (10^3 *psi*)	*Total elong.* (%)	*Uniform elong.* (%)
Steel* with 0.21% C				
0	57	78	28	17.5
1.7×10^{19}	87	90	14	3.5
1×10^{20}	86	101	13.5	8
Steel* with 0.07% C				
0	27.5	51	45	29.5
1.7×10^{19}	82.5	82.5	9.5	0
1×10^{20}	97.5	98.5	8.5	0.5
Steel* with 0.05% C				
0	45.5	55.5	35	25
1.7×10^{19}	83	80.5	10.5	0.5
1×10^{20}	98.5	98	7.5	1

* Samples were normalized from 1,700° F and irradiated at 205° F maximum.

C	*Mn*	*P*	*S*	*Si*	*Al*	*Cu*	*Ti*	*Zr*
0.21	0.09	0.009	0.015	0.18	0.009	—	0.14	—
0.07	0.15	0.011	0.029	0.07	0.048	0.39	0.42	—
0.05	0.08	0.006	0.018	0.06	0.300	0.39	—	0.33

STRUCTURES, VESSELS

Although structural metals are among the most radiation-resistant materials, they are called on for vital and strenuous service in reactors. Thus even at moderate doses questions arise as to whether heat treatment and microstructure affect in-pile properties of irradiated steel more than carbon content itself does, to what extent does transmutation of even trace amounts of elements such as boron or tungsten change the properties of steel alloys, and to what extent are welds affected differently than the two components being joined.

Carbon Steels

Table 1 compares neutron-radiation effects on the tensile properties of two high-alloy ferritic steels (*2*). For both, (a) yield stress increases markedly, (b) ultimate tensile strength increases less and (c) elongation-to-fracture decreases. Since Carilloy T-1 contains boron, we would expect radiation to change it more than a boron-free steel (the $B^{10} + n \rightarrow Li^7 + He^4$ reaction "fragments" give a higher total kinetic energy—thus initially displacing a larger number of atoms), but at the high doses the boron-reaction-product-induced changes apparently are overshadowed by the stability imparted to the Carilloy T-1 by its fine-grained quenched-and-tempered structure.

Based on experiments with ASTM-A302B steel, molybdenum might not be entirely effective in preventing "blue-brittle" effects in irradiated steels (*3, 4*). With this exception, carbon and low-alloy steels obey the rule that yield strength depends strongly on irradiation temperature (*5*). While tensile strength generally increases less than yield strength, in some cases higher-temperature irradiations lead to a larger increase in tensile strength. Still, true fracture stress is not greatly reduced. While uniform elongation sharply reduces after high doses and necking may begin at or soon after yielding, the area reduction does not decrease greatly until neutron exposures become high.

on Reactor Metals

Fine grain size. Fine-grain carbon steels show less shift in impact ductile-to-brittle transition temperature than do coarse-grain carbon steels; they also appear insensitive to neutron dose while coarse-grained steel is sensitive. The threshold dose might depend on both irradiation temperature and type of steel (*6–10*). In high-purity iron there is no clear superiority of the fine-grain metal under impact load conditions.

The superior resistance of fine-grain steel (2,000 and 500 grains/mm²) also is shown by En2 steel irradiated at 122–212° F and tested at −320° F (*7, 11*). Irradiated coarse-grain tensile samples are brittle after exposure to 1.5×10^{19} nvt, while fine-grain samples are still fairly ductile even after exposure to six times that dose. All unirradiated control samples were ductile. The brittle-to-ductile transition temperature of fine-grain specimens increases from −15° F (for unirradiated controls) to 97° F for samples irradiated to 1.9×10^{19} nvt (*7*).

Other factors. Fine grain size alone does not necessarily make a steel more resistant to radiation (*12, 13*). Two of the low-manganese steels in Table 2 contain much less carbon than the third. Even though all are fine-grained and essentially ferritic, the low-carbon steels have less uniform ductility after exposure to 1.7×10^{19} nvt (fast). On the basis of these results alone, it is suggested that the ferrite rapidly loses its ductility upon irradiation. However, in steels with a range of ferrites containing various amounts of manganese, nickel, chromium and molybdenum, no differences are noted on the maximum-energy absorption in the ductile region of impact transition curves (*14*). Thus it seems that the annealing-temperature dependence of radiation-induced effects might be a function of the amount of carbide and nitride formers in the individual type of steel—and that the carbide platelets in the higher-carbon steels (rather than grain sizes) give greater resistance to ductility loss (*15*).

If this latter assumption is true, heat treatment and microstructure also must play an important role in the susceptibility of low-alloy steels to radiation effects (*6, 8*). If transition-temperature increases are the criteria, the impact-test results in Table 3 imply that a quenched-and-tempered structure in low-alloy steels is the more radiation-stable. But the same test results also imply the reverse (if absorbed-energy values are the criteria)—quenched-and-tempered structures are less radiation-stable. Thus further fundamental study is needed to evaluate individual effects, since they seem somewhat independent of one another.

TABLE 3—What 10^{20} nvt Does to Notched-Bar Properties of HY-65 Steel after Various Heat Treatments

Transition temperature (°F)		*Maximum ductile energy (ft-lb)*	
Before	*After*	*Before*	*After*
Normalized and tempered			
−120	234	7.8	4.6
Austempered and tempered			
−160	160	7.8	4.4
Quenched and tempered			
−173	75	7.8	4.0

Transmutations Can Effect, Too

The direct effect that fast neutrons have on metal lattices is readily recognized; less well appreciated are the indirect property changes that can result from foreign atoms produced by transmutations following slow-neutron capture. For example, boron (which transmutes to Li^7 and helium) and tungsten (which transmutes into rhenium) can lead to problems more serious than their concentration in some steels would indicate.

Consider a steel with a mere 0.004 wt % boron added to increase hardness. Because of boron's low atomic weight this means that 0.02% of the atoms are boron—17% of which are high-cross-section B^{10} atoms. The complete transmutation of this quantity of B^{10} (not unreasonable in today's high-flux reactors) produces an amount of helium equal to 12% of the volume of the steel at standard temperature and pressure. Clearly this amount of interstitial gas can have significant effects.

Experiments show that helium gas formed by transmutation shortens the creep-rupture life of Inconel that contains only 0.001–0.005 wt % boron. Apparently the helium collects into small gas pockets that weaken the grain boundaries and create stress-raising voids. If on top of this the Li^7 enhances boundary deformation, the grains separate (46). Unfortunately, quantitative prediction of such effects lies beyond present-day metallurgical theory, but Oak Ridge plans experiments to define the effect of boron.

Stainless Steels

Under impact or shock loads, austenitic stainless steels, 18-8 types and certain nonferrous metals offer the advantage of higher initial ductility and lack of entirely brittle failure (*6, 15*). Since there is no definite ductile-to-brittle transition temperature for these materials, there is not as much concern about reactor vessels made of them as there is for vessels made of carbon steels. Radiation effects will be less severe on stainless-steel reactor vessels operating above 600° F than on carbon-steel vessels below 600° F.

Tests of annealed type-347 stainless steel (small multiple-notch tension specimens irradiated to 4.3×10^{20} nvt in EBR-1) confirm that its hardness and tensile strength behave similarly to plain carbon steels—they increase up to a certain maximum exposure (*16–18*). While for the initially annealed material there is a linear relationship between measured properties and integrated flux, some-

what erratic results on cold-drawn stock indicate incipient stress relaxation. Evidence of the incipient annealing process and the activation energy for thermal healing can be related to the integrated flux.

After irradiation at temperatures below 500° F, in both cold-worked and annealed type-347 stainless steel, (a) yield strength rises more rapidly than ultimate strength so that the yield/ultimate ratio approaches a value of 1, (b) area reduction decreases very little with decreasing doses, (c) elongation decreases continuously with increasing doses in annealed material and eventually saturates in cold-worked material and (d) a drop in load yielding occurs.

The energy of fast neutrons precipitates ferrites in type-347 stainless steel by dissociating the columbium carbide and displacing its components (*19*). As shown in Fig. 1, the mechanical effects of fast neutrons (higher hardness and tensile strength but lower ductility) on type-347 stainless steel can be annealed out at temperatures as low as 930° F. But such postirradiation heat treatment promotes formation of a heavy uneven carbide at the grain boundaries (as shown in Fig. 2) because the carbon is in a freer state after irradiation. The effect of this solid-state change on the impact properties of the austenitic material has not been determined.

Ferritic stainless steels. Whether irradiated or not, ferritic stainless steels generally do not show a ductile-to-brittle transition temperature above −320° F. However,

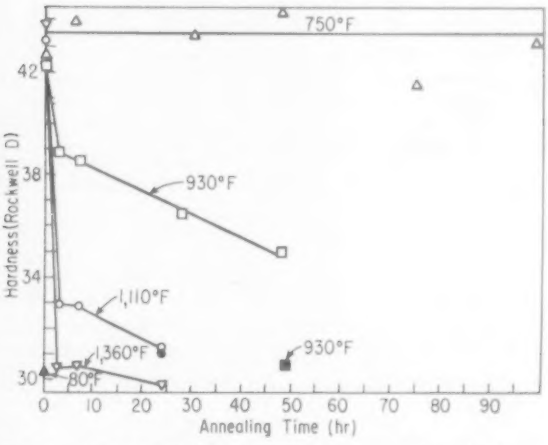

FIG. 1. HOW VARIOUS TEMPERATURES anneal out hardness in type-347 stainless steel caused by exposure to 2×10^{21} nvt (solid symbols represent unirradiated control samples)

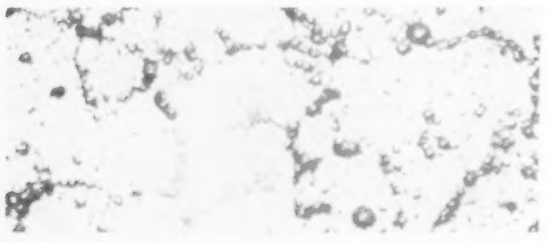

FIG. 2. ANNEALING TYPE-347 stainless steel (after exposure to 2×10^{21} nvt) for ½ hr at 1,360° F promotes precipitation of heavy uneven carbide at grain boundaries (oxalic acid etch; 1,000×)

Trends in Brittle-Fracture Studies

Neutron irradiation lowers the ductility of most metals used for reactor structure and containment. This, plus the fact that a swift reactor power change causes a thermal shock that can have an effect similar to a sudden impact, makes prevention of brittle failure an essential element in reactor design. Experiments have shown that irradiation temperature and material purity have an important effect on neutron-induced brittle fracture of carbon steels. The quest for a tighter understanding of brittle fracture has led toward emphasis on Charpy V-notch tests.

Temperature. Irradiation of steel at 575° F and higher leads to less change than irradiation at lower temperatures—but these effects vary even in steels of similar types. This variation as a function of material and radiation dose is not yet understood, which is a situation typical of our generally limited quantitative knowledge of radiation effects above 200° F.

Purity. Radiation changes the ductile-brittle transition temperature of vacuum-melted high-purity iron-carbon alloy much less than it does that of commercial steels. Thus there appears hope of improving metals' resistance to radiation-induced susceptibility to brittle fracture through controlling alloy composition and quality.

Charpy vs. Izod tests. Subsize Izod specimens were used in early experiments because of limited irradiation space available in reactors. But there is no uniformity among the numerous subsize tests and—contrary to the case with Charpy V-notch tests—there are little or no data relating subsize tests to service behavior. Thus, as more irradiation space has become available, emphasis has shifted to standard Charpy tests for brittle-fracture studies (46).

a group of type-446 specimens exposed at 205° F to 10^{20} nvt (fast) show a transition temperature between 350 and 400° F; no transition existed for the unirradiated controls (*20*). Since nitrogen is added intentionally to type-446 ferritic stainless steel, this effect might be caused in some way by radiation-induced mechanisms that affect the nitrided constituents. Nitrided type-410 stainless steel in fatigue shows increased endurance limits of 20–30% after irradiation, although there is no noticeable change in the over-all notch effect of irradiated specimens (*6*).

Welds

Primary among the unique problems of reactor design is evaluation of welded structures and internal stresses under high neutron doses at various temperatures. With the nick-bend technique as a criterion for weld integrity, the lower than normal loads that start fracture in irradiated material indicate that some embrittlement occurs in welds joining ASTM-A212 pressure-vessel plates (*6*). Analyses of the impact properties of three zones in welded sections of low-alloy and mild steels show increases in the ductile-to-brittle transition temperature after low-temperature irradiation (*6, 21–23*). Insufficient specimens make it difficult to analyze such variables as fabrication differences experienced by the parent metal, weld deposit procedures (hand weld vs. union-melt weld), postweld treatments

TABLE 4—How 5×10^{19} nvt (Epithermal) Changes Mechanical Properties of Various Metals

Testing temp. (°F)	Yield strength (10^3 psi)		Ultimate strength (10^3 psi)		Elongation (%)	
	Before	After	Before	After	Before	After
Zirconium (cold-worked)						
78	107	106	124	124	3.5	4.2
194	103	96	115	115	2.7	3.4
320	92	90	101	106	1.9	2.9
390	87	82	91	93	2.1	2.7
Molybdenum						
78	93.7	99.4	99.8	104.3	23.6	22
194	80.3	93.3	90.5	93.5	23.8	18.4
390	70.4	85.5	74.6	85.9	2.8	5.8
Tungsten						
390	148	131	173	173	2.4	4.2
Nickel						
−320	38	90.8	88	105	32	15
−108	38	75	70	78	41	24
78	36	62	59	63	34	23
390	34	54	51	59	27	19

(stress-relieved vs. as-welded) or combinations of the two latter criteria.

However, with tensile strength as the criterion for weld integrity, tests on welds between heavy sections of similar material indicate that the weld metal might be more sensitive to radiation than the parent metal (*2*). With impact test as the criterion, the reverse is true for heavy sections; the impact characteristics of the weld metal appear better than those of either the base metal or the heat-affected zone.

Postirradiation welding. Except for the difficulties of working on radioactive material, irradiation to only 10^{19} nvt does not affect the weldability of A212 steel (*18*). But doses above 10^{24} nvt at less than 500° F might result in defects after welding—with some correlation with mechanical-property changes due to irradiation. Impact and tensile data on irradiated USS T-1 steel welded with Arcos E-12016 electrodes (using subsize specimens) indicate that fine-grain and hardness criteria might not be the controlling index of radiation stability. But the effects of radiation on boron (used in alloying Carilloy T-1) might contribute to the over-all changes observed.

CLADDING AND LIGHT METALS

Irradiation behavior of today's claddings—as well as of the newer metals and alloys needed for higher-power reactors—promises to direct the trend of reactor construction. Table 4 shows the effects of radiation on the mechanical properties of various metals (*24*). As expected, there is a marked increase in yield strength, a smaller increase in ultimate strength and a moderate reduction in elongation to fracture. However, some unusual features deserve further discussion.

Zirconium

Sufficient data are available to use alloyed and unalloyed zirconium in many reactor types. Still, there is considerable disagreement regarding the basic causes of embrittlement of zirconium alloys used as fuel cladding in water-cooled reactors (*25*). The pitting and cracking have been attributed to some combination of hydrogen embrittlement caused by dissociation of the water, radiation dose and energy, impregnation of fission products from the fuel, interdiffusion between the fuel and cladding and the temperature at which the material operates (*26, 27*).

In sodium- and NaK-cooled systems, cracking of zirconium and Zircaloy-2 cladding under irradiation appears to depend primarily on the irradiation temperature—rather than on the presence of sodium or NaK as was supposed previously. On the basis of available data, a critical irradiation temperature in the vicinity of 500° F is believed to exist (*28*). Above this, cracking does not occur, while below cracking may occur at low average cladding strains of about 1–2%. At the lower temperatures, secondary factors important in determining whether or not cracking occurs are hydrogen content, orientation, interdiffusion and fission-product impregnation.

Apparently, pure ZrO_2 does not undergo phase transformation under neutron bombardment, although a monoclinic to cubic phase change takes place in oxidized zirconium alloys containing up to 5 wt % of either vanadium, chromium or tantalum under moderate neutron dose (*29*).

Aluminum

Aluminum is affected little by exposure to neutrons and has proved itself as fuel cladding in low-temperature research, test and production reactors where it is not subjected to appreciable stresses. In-pile measurements show that the creep rate of high-purity aluminum does not increase significantly during a 50-day irradiation in a fast flux of 1.3×10^{12} nv (*30*). However, creep of aluminum cladding will be enhanced unless there is a barrier to prevent interdiffusion between the fuel and cladding (*26*).

Beryllium

Beryllium is a potential fuel cladding material for several gas-cooled power reactors. But large changes are expected in the properties of beryllium because of two reactions: an $(n,2n)$ reaction resulting in two atoms of

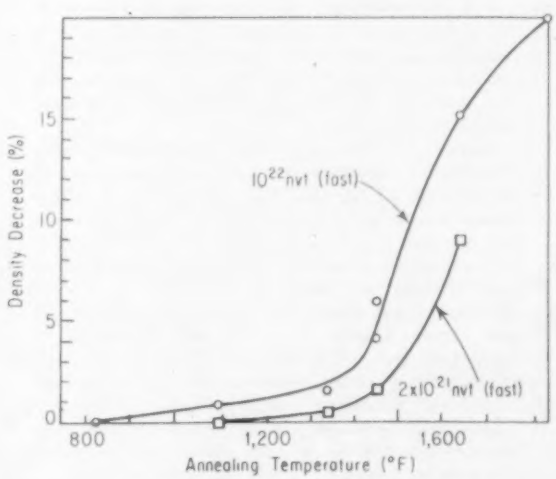

FIG. 3. BERYLLIUM SWELLS when annealed after irradiation

TABLE 5—Radiation Effects on Reactor Control Materials

Control material	*Est. max. burnup supportable (atom %)*	*Swelling at max. burnup (%)*	*Ductility reduction at max. burnup (%)*
Stainless-steel:boron alloys	2.0 to 2.5	2.0–2.5	Essentially complete
Titanium-boron alloys	2.0	6.0	Essentially complete
Zirconium-boron alloys	2.0	6.0–20*	Essentially complete
Titanium-boron dispersions	1.5	≦1.5†	20 or less
Zirconium-boron dispersions	1.5	≦1.5†	20 to complete‡
Aluminum-oxide:boron-carbide ceramics	0.7	1.0	
Aluminum-oxide:zirconium-boride ceramics	0.7	1.0	
Europium oxide dispersed in silicon-free alloys	Non-burnout poison	Negligible	≦15§
Stainless-steel:gadolinium-oxide dispersions	Non-burnout poison	Negligible	≦15§
80-silver:15-indium:5-cadmium	Not established	Slight	Extensive¶

* Strongly temperature-dependent. † Depends on cladding thickness and type of boron-containing material used. ‡ Depends on temperature. § Depends on fast-neutron flux. ¶ Not a problem in present cores with moderate lifetimes.

helium, and an (n,α) reaction resulting in two atoms of helium and one of tritium. About 2 cm^3 of gas is produced per cm^3 of beryllium at 10^{21} nvt (fast) (*31, 32*). As shown in Fig. 3, postirradiation annealing above 1,470° F results in significant swelling (*30, 33, 34*).

Other Claddings

Molybdenum. Brittle failure of fuel cladding is highly undesirable; it would be better if cladding were to deform plastically when overloaded. Although irradiation causes a maximum shift in the ductile-to-brittle transition temperature of molybdenum at about 750° F, the amount of change as a function of fast-neutron dose is unknown for loading conditions of an expanding fuel element. Since there is doubt as to the ductility of irradiated molybdenum, its use for cladding fuel should be delayed until high-exposure irradiation experiments are performed on reference fuel elements as well as on the material itself.

The yield strength of unirradiated molybdenum depends strongly on temperature, decreasing from 94,000 psi at 78° F to 70,000 psi at 390° F. After irradiation, yield strength increases but, as shown in Table 4, the increase is much greater at 390° F than at room temperature. Irradiated molybdenum also develops a marked yield point when tested at 78° F after an anneal at 390° F. This behavior, which is in direct contrast with nickel and copper, is caused by submicroscopic changes—probably lattice defects that impede slip and raise the Mo flow stress-temperature curve (*24, 35*). Actual changes in the lattice parameter, X-ray line width and microhardness of commercial molybdenum are observed after irradiation at 95° F to various fast-neutron exposures ranging from 6.5×10^{16} to 1.2×10^{20} nvt (*36*). The lattice-parameter vs. neutron-exposure curve for Mo maximizes near 5×10^{19} nvt, and at 1.2×10^{20} nvt a net decrease occurs from the preirradiation value. In most other metals lattice vacancies and interstitials increase mobility and tend either to agglomerate or annihilate each other faster at high temperatures.

The yield stress of molybdenum also seems to have an anomalous dependence on grain size (*37*). Point defects caused by irradiation might strengthen subgrain boundaries to make them more opaque to slip dislocations than ordinary grain boundaries.

Niobium. Niobium apparently behaves very similarly to molybdenum when exposed to radiation. After about 10^{20} nvt at 60° F, yield strength increases from 61,000 to 77,000 psi (*38*). Annealing this material between 260 and 345° F causes a large increase with the formation of a yield drop, or yield point, at the start of deformation.

Stiffening vs. Stress Relaxation

Neutron irradiation reduces the ductility and strengthens metals by decreasing uniform elongation and increasing yield strength, respectively. Although in-pile creep tests have been attempted for some time, there has been disagreement in results. But a recent in-pile tensile experiment shows significant relaxation of stress after long fast-neutron exposure at less than 212° F (*47*). Confirmation is needed at various temperatures.

While there is still considerable disagreement among investigators regarding the total relaxation that can be expected, it appears that the degree of stress relaxation during a hold time in thermal cycling will be more if the sample is in tension than if it is in compression (48). The combined effects of stress and radiation are neatly demonstrated by the irradiation of helical springs made of Haynes Alloy-25 and Inconel-X wire along with control samples of unstressed wire. A dose of only 6×10^{18} nvt (fast) in 560–600° F water increases the spring constant 5–8% and decreases free length 2–3%. But the plastic-flow curve of the unstressed control wire changes only slightly—and the effect of flowing water, if any, is not factored into this evaluation (49).

CONTROL MATERIALS

Except for high-temperature gas-cooled reactors, for which there are as yet no reliable economical control

materials, the designer has a choice of suitable materials for use over a fairly wide range of reactor applications. Table 5 summarizes how radiation affects various control materials (*41*). Requirements of low-temperature research and production reactors are satisfied by boron and cadmium. Although boron–stainless-steel control rods of high-flux test reactors have burnup limitations because of property changes under irradiation, a ductile network is held at higher B^{10} loadings by using enriched boron.

For power reactors, the choice of low-cost available control materials with demonstrated performance is limited to boron-containing materials. Hafnium is attractive but expensive and relatively unavailable. The silver-cadmium-indium alloys and europium-oxide–stainless-steel dispersions appear feasible but are not yet evaluated fully for a variety of applications.

Rare earths. The rare-earth dispersions are least affected by neutron bombardment since, as with hafnium, neutron capture causes only an (n,γ) reaction and high local heating without generating a daughter element. Several Eu_2O_3–stainless-steel-dispersion control rods are performing satisfactorily at 500° F.

Ag-In-Cd alloys. The transmutation of indium to tin causes small volume changes. But since the alloy lacks stiffness, irradiation actually improves the short-term mechanical properties.

Boron-containing materials. Quite the opposite is true for boron-containing control materials, since neutron capture by a B^{10} atom produces lithium and helium, which have a much larger combined volume than the parent. Fortunately, it is relatively simple to accommodate the gases generated by (a) allowing space or a manifold for the gases to flow into, or (b) using boron as a compound that can contain appreciable amounts of gas on a microscopic scale (with this method, boron dispersions can support larger burnups than alloys). Even so, boron dispersions are not satisfactory for use as control materials for long-life cores at temperatures exceeding 600° F (*42*). Although the natural boron compounds are more stable than those that are enriched in B^{10}, natural boron lowers the poison effectiveness and increases the loading required. Thus it appears that the better approach is to allow space or a manifold for generated gases to flow into.

Zr-base B alloys. In zirconium-base boron alloys, there is evidence that the lithium is mobile and diffuses from the original ZrB_2 particle site into surrounding regions of the alloy (*43*). This increases the extent of the radiation-affected areas by lithium migration primarily, rather than by helium formation.

Ti-base B^{10} dispersions. Reactor irradiation of titanium-base enriched-B^{10} dispersions increases yield and ultimate strengths and correspondingly decreases ductility (*44*). The boron particles grow and at high doses the B^{10} particles crack internally.

Boron–stainless steel. The property changes are different for 15% vs. 25% burnup of the B^{10} atoms in an alloy of 18-8 stainless steel containing 1% boron as 93% enriched B^{10} (*45*). This erratic and brittle behavior is caused by stress-raising discontinuities (in the stainless steel surrounding the boride inclusions) that result when neutrons transmute boron into helium, which collects in voids that grow as burnup proceeds.

CONCLUSION

There are only limited data available on materials for special application—such as magnetic compounds, thermal insulators and noble metals. Also, too little is known about the radiation stability of precipitation-hardening structural alloys exposed at or near the aging temperatures. Because of higher design loads, higher operating temperatures and the possibility of cyclic temperature transients, irradiation experiments with all types of reactor materials must continue so as to reduce the "ignorance factors" now going into component designs.

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RADIATION α β n γ EFFECTS

Radiation Pulses

Ionizing radiation can introduce spurious signals, distort normal ones and cause permanent malfunction. Inspecting responses to short pulses sometimes reveals the mechanisms involved

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RADIATION PULSES acting on electronic components cause several kinds of effects. For convenience let us classify them by their dependence on time: "dose" effects are those that persist and depend on the total dose delivered; "rate" effects are those that exist only during the radiation pulse and depend on dose rate; "relaxation" effects are those that die away gradually after a pulse. We see that dose effects are permanent; rate and relaxation effects are transient. Whether a transient effect is called "rate" or "relaxation" depends on whether its time constant is short or long compared with the pulse length.

The electronic engineer wishes to know how basic radiation-effect mechanisms affect his circuits. In general radiation will induce potentials, cause leakage and alter the performance of his circuit elements. His task, then, is to analyze performance in terms of these effects and attempt to find a systematic approach to design principles that will yield radiation-resistant circuits.

Fundamental Mechanisms

As is true of all radiation effects, those that follow pulses of radiation can be attributed mainly to two phenomena: ionization and atomic displacements. To some extent one can recognize the two separately; first, by studying the radiation that causes them and second, by looking at the effects.

Although all types of radiation cause ionization, displacements come only from the more energetic types. Electrons and gamma rays, for example, usually produce only a small number of primary displacements. With neutrons and heavy charged particles, on the other hand, enough energy is delivered in atomic collisions that primary displacements cause secondary displacements. In fast-neutron irradiation primary knock-on atoms are so energetic that a cascade process involving thousands of displacements can occur.

The second means of separating ionization and displacements is by watching the time scale of effects that follow; usually dose effects are caused by displacements and both rate and relaxation effects come from ionization.

It is important to realize, however, that ionization and displacement effects can not always be clearly separated. In the alkali halides, for example, ionization energy can be converted into atomic displacements quite efficiently near dislocations (*1*). On the other hand, because of their loose coupling to the lattice, conduction electrons in a metal can not be expected to cause displacements.

Permanent or Transient?

The relation between permanent and transient effects will differ as one progresses from metals to semiconductors and from semiconductors to insulators. It is probably true in metals and to a smaller extent in semiconductors that ionization energy can be neglected in determining atomic displacements (*1*). (How much this is true in semiconductors depends on the relative amount of ionic binding present.) Thus a fairly clearcut distinction can be made between permanent and transient effects.

Transient radiation effects in metals, on the other hand, insofar as they result in ionization, are probably not observable; any charge separation is almost instantly neutralized. But dose effects are observable; they result, for example in resistivity and hardness changes.

In semiconductors transient effects are observable (*2*); they cause momentary changes in electrical and optical properties. One can assume that a burst of radiation causes a change $\Delta n(t)$ in the number of excess charge carriers, which decays exponentially so that $\Delta n(t) = \Delta n(0)e^{-t/\tau}$. The time constant τ depends on the recombination process (*3*). Permanent changes in resistivity also occur; for example, n-type germanium can be converted to p-type by neutron irradiation (*4*).

In both organic and inorganic insulators ionization effects can persist so that it is hard to draw a clear distinction between permanent and transient effects. In alkali halides ionization produced by X- or gamma rays results in a persistent coloration caused by electrons trapped in negative-ion vacancies.

Electronic Malfunctions

The practical question to electronic designers is whether irradiation can cause a system malfunction. Even when materials in a system experience transient effects, malfunction may not occur. If one does occur under irradiation, however, a thorough knowledge of the effects produced in component materials is necessary if one is to eliminate the malfunction systematically.

In this connection one must consider both the radiation effect and the function of the component. For example, semiconductors are usually parts of circuits. A thin film of silicon, however, is sometimes used as an optical filter in front of an infrared detector; here one is concerned with optical properties rather than electrical response.

In semiconductors one expects performance to be affected mainly by the introduction of minority carriers.

and Electronics

Thus one expects tunnel diodes, operation of which depends on majority carriers, to be less affected than conventional transistors in which minority carriers govern operation.

Ferrites, now used for microwave switching, may show peculiar behavior if they are subjected to transient magnetic fields and energetic radiation. There are no data yet to verify these assertions about ferrites and tunnel diodes.

Behavior of quartz is important in conventional crystal oscillators. X-rays reduce elastic constants in both BT- and AT-cut crystals, and this action reduces oscillation frequency (*5*). At most the effect amounts to 0.1% frequency change, and it probably results from ionization of silicinations (*6*). This is probably a permanent effect, but transient effects may exist also. Neutron irradiation to $\sim 10^{18}$ n/cm^2 produces permanent point defects (*7*).

Circuit Performance

The designer of an electronic circuit that is to work under radiation pulses must face two kinds of transients: one is the noise transient, a pulse induced in the circuit by any of the radiation-effect mechanisms; the second is a transient distortion of normal signals from a temporary change in operating characteristics. The main cause for changes in operating characteristics is induced leakage, which changes circuit impedances.

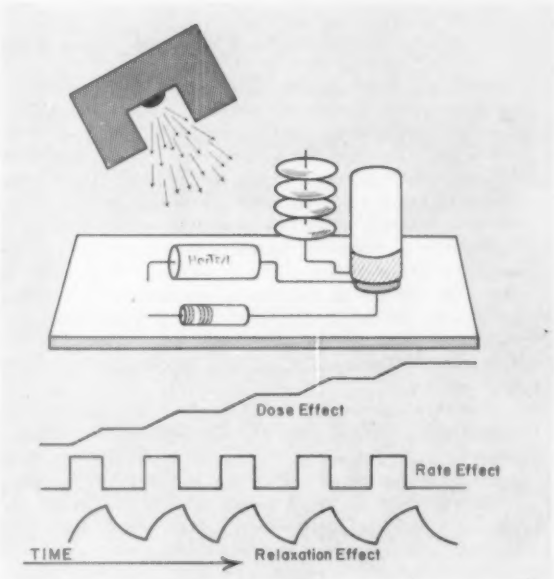
In the mathematical analysis of a circuit, pulsed-radiation effects are introduced into the network equations according to the mechanisms involved. Changes in properties of circuit components become time-dependent variations in circuit parameters. External leakages generally become additional loops in the analysis. Charge scattering is equivalent to the introduction of current generators; so it becomes additional driving-force terms in the equations. All of these transient effects are, of course, introduced during a finite time interval, typically a few times as long as the radiation pulse.

From mathematical analysis and test results come general principles for design of radiation-resistant circuits. As an example: wherever possible use small-impedance circuitry. Of two transistor flip-flops with identical circuit geometry and transistors, we found that the one designed to have small impedances was unaffected in tests that disabled the large-impedance model. For small impedances one must make sacrifices in larger currents.

Some types of circuits are particularly vulnerable to radiation pulses. Like the flip-flops we have just mentioned, other trigger circuits may be prematurely triggered or prevented from triggering on command. Oscillator circuits used for time bases or reference frequencies may suffer affects ranging from a transient phase or frequency shift to complete disablement (*8*). Small-signal amplifiers and preamplifiers have already demonstrated very large induced transients (*9*).

Circuit Components

There are various ways in which transient radiation effects show themselves in such circuit components as resistors, capacitors and diodes. Ionization and excitation produce transient changes in electrical properties. In normally insulating regions, ionization can produce leakage and breakdown; external leakage can occur across surfaces or through air. Charge scattering (for example from photoelectric or Compton collisions) causes extraneous currents.



RADIATION EFFECTS ON ELECTRONIC SYSTEMS are conveniently classified as dose effects, rate effects and relaxation effects depending how rate of change compares with pulse duration

Resistance can decrease with release of new current carriers or increase with production of new scattering centers. From present data it is difficult to determine which effect is predominant. We have observed transient resistance increases of ~1% in 2-watt carbon-composition resistors exposed to gamma intensities of 2.6×10^6 r/sec produced by 10-μsec neutron-gamma pulses. Deposited carbon-film resistors usually show resistance changes of 3–5% in 10^{16}-n/cm^2/sec, 10^6-r/sec neutron-gamma pulses of ~100-μsec duration. In some instances the increase was as great as 18%. Some wire-wound resistors show negligible change; others decrease in resistance as much as 20%. This change is probably a leakage phenomenon rather than a true conductivity change.

In general large resistors show greater fractional changes than small ones. This is what one would expect because leakage resistance, which is effectively in parallel with internal resistance, depends mainly on surface area.

Charge scattering is evident from pulses that occur when no potential difference is applied to the resistor. From a 2-watt carbon-composition resistor we have observed 1 μa in 10-μsec pulses of 2.6×10^6 r/sec. This current should be independent of resistance value and proportional to physical size.

Capacitors suffer mainly from ionization-caused leakage through and around the dielectric (*8*). Any capacitor is susceptible to this effect, but electrolytic and paper ones are particularly sensitive. Reduction of leakage resistance to 4–5 megohms is induced in 0.01-μf paper capacitors

Chemists, Too, Find Transient Responses

While electronics engineers are asking what happens in the microsecond that follows arrival of a pulse of radiation, chemists are asking similar questions: What molecular fragments are created in the pulse? How long do they last? How can you affect their populations and lifetimes? What becomes of them? How can you work with them to affect the final product? Members of a recent Gordon Research Conference on radiation chemistry got a good look at how scientists are attacking these questions. Their methods vary from one end to the other of the long list of chemical techniques, but particularly prominent at the Gordon conference were chemical-kinetics theory, observation of pulses, irradiation of specimens at very low temperatures and mass spectrometry.

If you are a theorist, your problem may be to predict the radiation products in a given chemical system. Perhaps you begin by writing down the various equations that represent conceivable reactions ($H_2O \rightarrow H + OH$; $OH + OH \rightarrow H_2O_2$, etc.). If you make simple assumptions about reaction rates, your computations will tell you what final products to anticipate, how temperatures will affect the yields, what will be the effect of a radical scavenger and similar things.

Those chemists who observe pulses have taken over many techniques from flash photolysis. For example, they excite a specimen with a pulse of light or ionizing radiation. Immediately afterward, in time intervals measured in microseconds and milliseconds, they pulse an analyzing light source and look for absorptions at wavelengths known to represent species of interest. Rates at which these absorptions disappear indicate how many species are involved in the disappearance, how large are cross sections, etc.

Low-temperature irradiations examine the same kinds of questions. With this technique one hopes to trap the intermediates. Then one can look at them with somewhat more leisure than is available to the room-temperature pulse observer. One method of inspection is electron-spin-resonance spectral analysis. Another is to allow the specimen to rise in temperature. With constant heat flow, distortions in the time-temperature curve indicate exothermic and endothermic reactions as molecular species disappear.

Mass spectrometrists make their molecular fragments, free radicals and ion molecules by firing electrons at gas that is entering the apparatus. Then they accelerate the various species with electric fields and analyze with magnetic fields. "Appearance potentials" indicate how much electron energy is required to produce a certain member of the spectrum. Variation of accelerating potentials gives a measure of lifetime. In an extension of techniques, some are causing ion molecules to collide and then looking for products in their analyzer systems.

by neutron-gamma pulses from Godiva II at Los Alamos (10^{16} n/cm²/sec; 10^6 r/sec; ~100 μsec). Leakage that is smaller by 50% occurs in electrolytic capacitors.

It is questionable whether an actual change in capacitance takes place as a rate effect. To produce such a temporary change one would have to produce a change in the polarizability of the dielectric; a change in equilibrium distribution of atomic electrons is required. But the lifetime of excited electrons is too short for this to be likely. It is difficult to separate capacitance change from leakage, but a bridge technique that is relatively insensitive to leakage shows no capacitance change greater than 1%.

Electron scattering can also occur from the dielectric and the two electrodes, but no data have been reported on this contribution.

Semiconductor diodes are nonlinear resistances and display the same effects as occur in ordinary resistors (*8, 10, 11*). Since forward and back resistances depend on different phenomena, however, radiation effects on one are greater than on the other. Forward resistance, depending on the movement of a generous supply of charge carriers through a lattice, is essentially unchanged by the radiation fields of existing facilities (up to 10^6 r/sec and 10^{16} n/cm²/sec). Back resistance, depending mainly on the supply of a small number of carriers, decreases as these carriers are released in the depletion layer. Decrease is proportional to depletion-layer volume.

Reverse-current pulses also occur in semiconductor diodes. In low-level germanium and silicon ones pulses of 10–100 μa are observed; power diodes exhibit pulses of 1–10 ma. Both neutrons (10^{16} n/cm²/sec) and photons (10^6 r/sec) appear to be effective in causing this behavior.

Internal- and external-leakage contributions are overshadowed by the high sensitivity of semiconductor diodes to reverse-current changes. So is charge scattering from the diode body, which should be small because of the small physical size of the diodes.

Transistors, like diodes, are principally affected by changes in conductivities of various regions (*10, 11*). Results are normally expressed as changes in current-gain factor β and zero-bias collector current I_{c0}. In general β decreases by at least 10% in the radiation fields of existing facilities (nv = 10^{16} n/cm²/sec; gamma dose rate = 10^6 r/sec). Typically I_{c0} increases by several hundred microamperes.

Infrared detectors act as resistors, but transient effects in them are complicated by slow intrinsic response. Thus the magnitude of an effect depends on the length of a radiation pulse. Lead sulfide is the slowest type that we have tested; in the 100-μsec neutron-gamma pulse of Godiva II we have observed an apparent decrease in resistance of 5–10% (much of it may be caused by leakage). Short bursts from plowshare devices would cause smaller changes.

Lead selenide cells are much faster, and we have observed resistance decreases of ~1%. Because of their fast response, the effect has a maximum with 20–30 μsec pulses.

We have observed no effect from charge scattering and expect it to be small because of the small physical size (~1 × 0.1 cm) of these devices.

Gas tubes are subject to breakdown caused by ionization of the gas. Leakage is of no interest here except as it can bring about breakdown. This effect can occur in a thyratron, for example, if changes of the anode potential influence the grid circuit. Charge scattering is probably

of no consequence in causing breakdown of these gas tubes.

Gas tubes operating in discharge, as cold-cathode types do in voltage-regulator applications, are relatively insensitive to radiation. We have observed a small increase in the discharge current (a few microamperes) in Godiva II exposures.

Other tubes we have tested for breakdown include thyratrons and transmit-receive tubes used in radar duplexing circuits. All exhibit breakdown in Godiva II fields. Grid bias required to prevent ignition of thyratrons increases by a few volts. In the short gamma pulse of a linear accelerator (10 μsec, 2×10^6 r/sec) thyratrons are unaffected. Either the neutrons from Godiva play a major role in the effect, or linac pulses are too short to permit ionization to build up to breakdown.

Coaxial cables display both internal leakage and charge scattering. Effects are small, but they can be important in small-signal or large-impedance circuits.

Charge scattering is evident when no potential difference is applied across the cable. In sold-dielectric cables the net effect leaves the cable with a positive charge on the central conductor (a net scattering of electrons outward). In partial-air-dielectric types such as RG62/U the net effect is the opposite; that is, a negative charge on the central conductor. The effect is much larger in the partial-air-dielectric type.

Internal leakage results from ionization, and several tests on solid-dielectric cable RG59/U indicate a leakage resistance that is nonlinear with applied voltage. The graph shows current produced in a terminating resistor as a function of applied voltage. Polarity is such as to create a crossover point; at some potential difference charge scattering cancels internal leakage. This crossover point can be useful in eliminating transient radiation effects on coaxial cables from terminal circuitry—an important consideration in experiments on components in which cables are used for telemetry.

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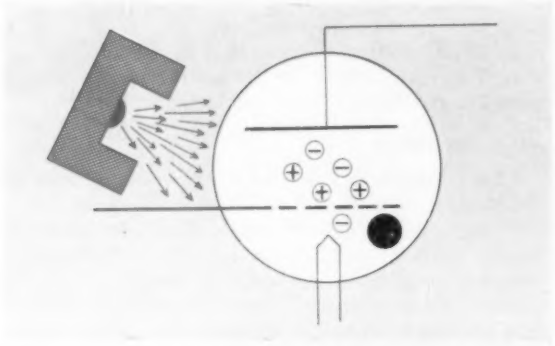
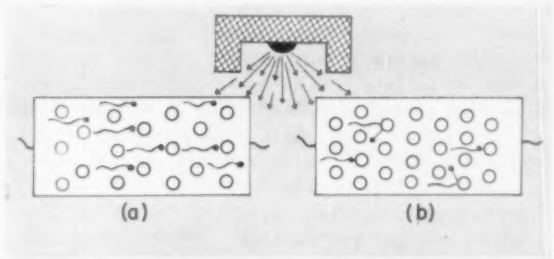
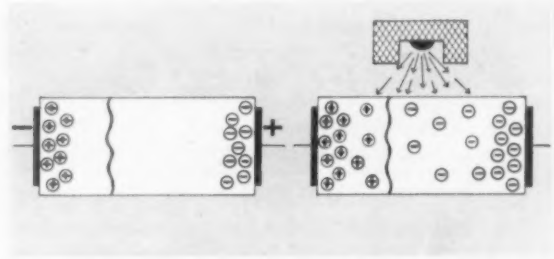


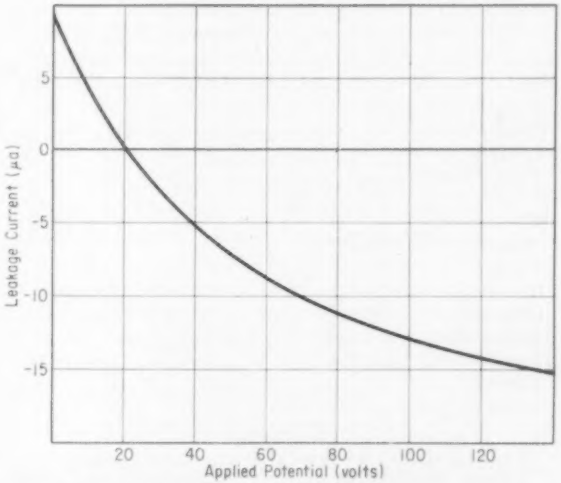
BREAKDOWN POTENTIALS CHANGE IN GAS-FILLED TUBES because radiation ionizes gas. Long pulses of neutrons and photons are considerably more effective than short neutron-free pulses



RESISTANCE INCREASES OR DECREASES with radiation as electrons are freed and scattering centers are created. Effect that predominates determines whether net result is increase or decrease



TRANSISTORS SHOW DECREASE OF BACK RESISTANCE as charge carriers are created in usually empty depletion region. Dependence on minority carriers makes effect large



CABLE INSULATION shows a nonlinear resistance decrease in radiation pulses. Charge scattering plays a part also, and two effects will cancel each other at some cross-over potential

Radiation Effects

Crosslinking and cleavage are radiation effects that are damaging to organic materials as well as useful for producing organics having unique properties. Advances in these areas are leading to materials with better radiation resistance and to new products, for example in the polymer field

By JAMES G. CARROLL and ROBERT O. BOLT, *California Research Corp., Richmond, California*

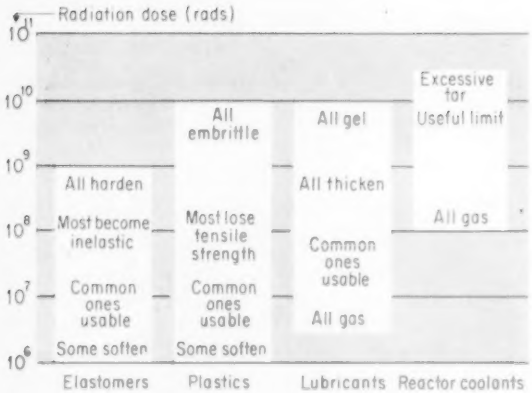


FIG. 1. RELATIVE SENSITIVITY of organic materials to radiation (10^3 rads are lethal to man; most metals and ceramics are usable above 10^{12} rads)

TABLE 1—Radiation Resistance of Base Oils

	*Radiation dose (10^8 rads)**	
	Threshold†	*Failure†*
Polyphenyls	50	500
Polyphenyl ethers	10	100
Alkyl aromatics	10	50
Polyglycols, Mineral oils, Methylphenyl silicones, Aryl esters	1	10
Silicates, Disiloxanes, Alkyl diesters	0.5	5
Phosphates, Alkyl silicones, Olefins	0.05	1

* Irradiations in inert atmosphere at moderate temperatures.

† Based on the most sensitive lubricant property, usually viscosity or acidity. Threshold dose is the radiation dose above which performance of a material is impaired. Failure applies to the dose at which a material becomes useless.

ORGANIC MATERIALS—lubricants, reactor coolants, plastics and elastomers—vary widely in their susceptibility to the effects of radiation. The radiation doses that these materials can tolerate are shown in Fig. 1. In addition to discussing the present understanding of this radiation-damage aspect, the following discussion also tells of current efforts to develop radiation processing as a means to improve the properties of plastics and elastomers.

LUBRICANTS

These materials comprise a base oil (75–>99%) and additives to influence specific properties, e.g., a gelling agent in the case of a grease. Since the sensitivity of additives to radiolysis limits their effectiveness at high doses, the stability of the base oil is the most important aspect of radiation resistance (*1*). The relative resistance of various base oils is shown in Table 1. Alkyl aromatics (*2*) and polyphenyl ethers (*3–5*) have received the most attention; the latter have proven best for high-temperature use.

Polyphenyl Ethers

Both substituted and unsubstituted polyphenyl ethers surpass conventional lubricants with regard to radiation-induced changes in physical properties, coking at 700° F and thermal stability (*6*). Wear properties in bench tests equal those of uninhibited diesters and are better than those of silicones and polyphenyls (*4*). Wear in more realistic bearing and gear test rigs is being evaluated; initial results indicate no unusual problems.

Although performance data are not yet available, greases using polyphenyl-ether base oils should have very high radiation stability.

Alkyl Aromatics

Alkyl aromatics have received attention for intermediate temperature and radiation conditions. A series of oils (*7*) and silica-gelled greases (*8*) based on inhibited alkylbenzenes is available and useful at up to 5×10^9 rads under moderate temperature and oxidizing conditions.

Alkyl(diphenyl ethers), alkylbiphenyls and diarylalkanes, when thickened with special aromatic polymers, are promising as hydraulic fluids for use at up to 400° F and $3–5 \times 10^9$ rads (*2, 9*). In particular, a $C_{14–16}$ alkyl (diphenyl ether) gave good test results. A fluid based on

on Organic Materials

isopropyldiphenylnonane (*10, 11*) resists effects of shear, oxidation and hydrolysis and should be stable up to 500° F in inert atmospheres. Though the fluid was not irradiated to failure, a gamma dose of 7.5×10^8 rads caused no major changes (*11*).

An alkylbiphenyl gelled with an aromatic additive has been used successfully as a grease (*12*). Although bearing life at 300° F decreased sharply after 7×10^8 rads in static tests, dynamic tests indicated good bearing performance. The grease operated for 2,500 hr at 6,400 rpm in an inert atmosphere in-pile bearing test (*12*); failure came only after 3.4×10^9 rads.

Conventional Lubricants

A grease composed of aromatic mineral oils gelled with an aromatic dye (Indanthrene Blue RS) (*13*) retained good serviceability in roll tests conducted in a gamma source to $\sim 4 \times 10^8$ rads. The tests confirmed that mechanical stability is the grease property most sensitive to irradiation.

A silica-gelled mineral-oil grease reportedly has good static radiation stability (*14*). The product operated in in-pile bearing rigs for 5,000 hr at 300° F in CO_2 to about 2.7×10^9 rads. These data show that special gelling agents give good results in selected conventional oils.

Some conventional mineral oils and greases have adequate radiation stability for central-station (*15, 16*) and surface-vessel (*17*) nuclear power plants. Several of these lubricants are useful to $\sim 10^8$ rads (*18*). Steam-turbine oils can be used to $\sim 5 \times 10^7$ rads (*19*). The oxidation inhibitors used in commercial fluids lose their effectiveness rapidly under irradiation and are almost completely ineffective at $\sim 10^8$ rads.

COOLANTS

In a year of operation, the first core of the Organic Moderated Reactor Experiment accumulated 958 Mwd with a mixed-polyphenyl coolant (16% biphenyl, 46% *o*-terphenyl, 32% *m*-terphenyl and 6% *p*-terphenyl). The success of the OMRE (*20, 21*) encouraged further research to reduce coolant costs (initial charge and make-up). Highlights of this continuing work follow.

Radiolysis Mechanisms

The nature of the radiolysis products (particularly the high boilers*) is being studied (*22*) as a basis for applying advanced chemical and physical separation schemes to the degraded coolant stream.

Hydrogen evolution may be the key to understanding polymer or tar formation. Various deuterated biphenyls have been irradiated to study this. The radiation attack is random with respect to the ortho-, meta- and para-hydrogen positions (*23*). Polymer formation, it is believed, proceeds via scavenging of hydrogen atoms by aromatics and subsequent coupling of these reactive species.

Biphenyl has also been irradiated at low gamma doses to determine intermediate products that may be precursors of undesirable secondary or final products (*24*). Hydrogenated polyphenyls were identified as intermediates.

Reconstitution, Radiolysis Inhibitors

Chemical methods are being studied to reconstitute degraded products. For example, catalytic hydrogenolysis has converted higher-molecular-weight polyphenyls to lower polyphenyls with only minor attack on aromatic unsaturation (*25, 26*). This technique was successful with OMRE high boilers, although some carbonation was observed (*26*). The method should eventually produce acceptable low-cost reactor-coolant feed material.

To determine the effectiveness of chemical additives (*27, 28*), fifty-six additives were tested in 2% concentration in OMRE coolant (*21*) to $3\text{–}4 \times 10^8$ rads of gamma radiation at 580°–750° F. Ten reduced polymer and gas yields significantly. A benzpyrene reduced both indexes by 50%. In other work (*29*), 5% thianthrene in biphenyl reduced decomposition by 20–30% in reactor exposures.

Low-Cost Coolants

Low-cost petroleum-refinery streams were investigated for coolant application. Preliminary data (*30*) indicate that the best materials are roughly equivalent in thermal stability at 750° F to polyphenyls at 920° F. No irradiations have yet been conducted. Other low-cost streams, e.g., phenanthrene and anthracene derivatives, appear promising in static irradiation tests (*63*).

Radiation Rate and Type

There is general agreement that, within a factor of 10^4, dose rate has little effect on polyphenyl degradation in non-oxidizing systems.

There is controversy, however, over the relative effects of radiation types. Experiments at Harwell and in the U. S. confirm that the polyphenyl starting material disappears at the same rate for gamma and for electron exposures. This is expected because the dominant effect of gammas is electron scattering via the Compton process. However, Harwell finds that polyphenyl decomposition yields from exposures in their BEPO reactor are significantly higher than from comparable electron irradiations (*31, 32*). The difference is attributed to the reactor fast-neutron flux. These differences are important in the extrapolation of radiation-effects data from one facility to another in which the neutron-to-gamma ratio is different.

Workers at Atomics International argue that these initial effects are of no practical significance if the high-boiler content is >17% (*33*). At these levels, decomposition rates are independent of the radiation type. In fact, at ~20% high-boiler content, Harwell data indicate lower decomposition rates than do AI results.

PLASTICS

Table 2 ranks plastics with respect to their radiation stability (*34, 35*).

Radiation alters the properties of plastics in the following ways: (a) Crosslinking increases tensile strength, hard-

* High boilers have boiling points exceeding that of the highest-boiling starting material.

ness and elastic modulus, though impact strength is not affected directly. (b) Scission reduces tensile strength and hardness. The changes can be related directly to radiation yields (G values*) for crosslinking and scission.

Polyethylene

Polyethylene, both the branched and the newer high-density, linear types, has been studied recently more than all other plastics combined.

The major effects observed are (*36*) hydrogen evolution, crosslinking, increase in unsaturation, destruction of crystallinity, color changes and oxidation (in the presence of oxygen). Crosslinking is the most important.

The mechanical properties of irradiated polyethylene depend markedly on dose and, where crystallinity is still present, on the temperature of testing. The following changes occur in the dose ranges indicated (*36*):

0–10 megarads. Branching and average molecular weight increase, often leading to increased tensile strength. Solubility and melting point are unchanged although bulk viscosity increases.

10–200 megarads. In this range, the rubberlike polymer consists of two phases—a sol (liquid colloidal dispersion) and a gel. Mechanical properties are modified by reduced crystallinity and the gel network. Properties are temperature-sensitive.

200–500 megarads. A transition region occurs when crystallinity has been almost destroyed, and density of crosslinks determines primarily the mechanical properties. The material is between the rubber-like and the glass-like stages and tends to crumble under stress.

>500 megarads. Polyethylene acquires a glass-like structure and has a high elastic modulus. The density of crosslinks is 10%.

Apart from crosslinking, the most noticeable chemical change in long-chain hydrocarbons when irradiated in air is increased main-chain unsaturation (*37*, *38*). This significantly affects the properties of polyethylene, particularly its susceptibility to oxidation. About half the hydrogen evolved results from carbon-carbon double-bond formation (*37*).

In the case of linear polyethylene, a material balance can be shown between hydrogen evolution, crosslinking and unsaturate formation between 77° F and 288° F by allowing for increased molecular weight due to end-linking (*39*). Such a balance could not be achieved for branched polyethylene. There is still lack of agreement on yields in polyethylene radiolysis (*37*). They range as follows:

G_{H_2}—3.0 to 5.7
$G_{crosslink}$—1.5 to 7.5
$G_{unsaturation}$—1.2 to 2.2

Differences in irradiation conditions, particularly temperature, and dosimetry probably account for a large part of the disagreement.

When polyethylene is irradiated in the amorphous state

TABLE 2—Radiation Stability of Plastics

Material	*Threshold dose for 25% change* (10^8 rads)*
Polystyrene†	40
Phenol formaldehyde (asbestos filler)†	40
Polyester (mineral filler)†	4
Polyvinyl chloride†‡	1
Polyethylene†	0.9
Urea formaldehyde†	0.5
Monochlorotrifluoroethylene‡	0.2
Cellulose acetate‡	0.2
Phenol formaldehyde (unfilled)†	0.1
Methyl methacrylate‡	0.01
Polyester (unfilled)†	0.01
Polytetrafluoroethylene (Teflon)‡	0.01

* Based on most sensitive property of plastics, usually tensile strength.
† Crosslinks. ‡ Scissions.

* G value is number of molecules of product formed per 100 ev of radiation energy absorbed.

General Effects of Radiation on Organics

Radiation changes organic substances by two main routes—crosslinking (or polymerization) and scission (cleavage). Hydrogen is evolved, and reactive sites formed in the residual organic molecule may lead to side reactions, depending on the molecular structure involved.

Crosslinking is manifested in liquids by viscosity increase; in solids by increased hardness and brittleness. Cleavage (the formation of lower-molecular-weight materials) results in less viscous liquids and softened (or even semifluid) solids.

Molecular structure is the largest factor influencing radiation stability, which varies 1,000-fold among organics. The most stable compounds contain aromatic rings; least stable are those having nonaromatic unsaturation.

The use of additives to protect less resistant materials is now widespread. Additives are most effective in the least stable materials, but even there rarely increase the radiation dose required for a given effect by more than a factor of 10.

In general, the gross effects of radiation, in the absence of time-dependent factors such as oxidation, depend only on dose and are independent of dose rate. Theoretically, very high dose rates should produce different behavior; but this has not yet been clearly established by experiment. There is recent convincing evidence that neutrons are more damaging than electrons, but most prior information supports the "equal-energy–equal-damage" concept regardless of the type of radiation.

Radiation does not change all properties of an organic material to the same degree. Thus, the critical property must be specified in considering the useful life of a given material. In any event, the longest lives will generally be obtained with compounds rich in aromatics and with radiation exposures in inert atmospheres at moderate temperatures.

(*40, 41*) or at 185° F (*42*), the resulting properties are superior to those of chemically-produced materials. Electron irradiation causes a fivefold increase in tensile strength in 1-mil-thick polyethylene sheets. A product of this sort, recently introduced by W. R. Grace (*43*), joins General Electric's Irrathene and Vulkene, Tube Investments' tapes and Grace's polyethylene-coated wire as a commercial material formed by irradiation.

Other Polymers

Methacrylate polymers predominantly cleave on irradiation (*44*). Comparison of the scission energies of poly(benzyl methacrylate) and poly(phenyl methacrylate) with those of nonaromatic methacrylate polymers shows a strong protective effect of the benzene ring (*45*). It is stronger for the benzene derivative, indicating an effect of ring position in the molecule. A similar protection by the aromatic ring is observed in copolymers of styrene and methyl acrylate, as shown in Table 3 (*46*).

Additives also protect plastics from radiolysis. Aromatic compounds are most effective in poly(methyl methacrylate) (*47*). A somewhat reverse effect was noted (*48*) for poly(vinyl chloride) plasticized with dioctyl phthalate. Although this plastic usually crosslinks above 2×10^7 rads, a polyfunctional monomer [e.g., poly(ethylene glycol) dimethacrylate] causes crosslinking at 10^6 rads and produces a material of improved thermal stability and tensile strength (Table 4). The additive apparently undergoes radiation-induced graft copolymerization.

Graft Copolymerization

Copolymerization is of interest in preparing new polymers. In random copolymerization, the product properties are often intermediate between those of the constituents. With nonrandom arrangements, it is possible to make ordered structures.

Copolymerization in which a desired side chain is grafted to a homopolymer backbone is particularly important (*49–52*). Several techniques are possible, including

1. Simultaneous irradiation of the polymer and the monomer.

2. Preirradiation of the polymer in vacuum followed by postirradiation contact with the monomer.

Table 5 shows some of the reactions possible with the first method (*36*).

Recently, polymers have been grafted by the preirradiation technique (*49*). Grafts of styrene to polyethylene were very sensitive to temperature and air and particularly

TABLE 3—Gel Formation*

Mole fraction of styrene	*Gel formed (%)*
0	97
0.18	53
0.59	17
0.83	Trace
1.00	0

* Styrene-methylacrylate copolymer gamma-irradiated to 10^7 rads in vacuum.

TABLE 4—Crosslinking of Plasticized PVC

*Radiation dose** (10^6 *rads*)	*Gel yield (%)*		
	% Poly(ethylene glycol)dimethacrylate		
	0	*10*	*20*
0	0	0	0
0.1		5	8
0.2		18	32
1.0		29	55
10.0		50	83
20.0	8		
40.0	65		

* Electron irradiations at 77° F.

to dose (Fig. 2). The copolymers were more homogeneous than those prepared by other irradiation techniques.

ELASTOMERS

Table 6 rates elastomers (high-molecular-weight flexible polymers) according to radiation resistance.

Scission and crosslinking (*53–55*) alter such rubber properties as tensile strength, hardness, elongation and compression set. The most significant recent development is the use of additives (antirads) to produce radiation-resistant rubbers (*56–58*).

Antirads

Several antirads incorporated in a carbon-black-filled natural rubber (*56, 57*) were irradiated in air, nitrogen and vacuum (Table 7). Scission was determined by stress-relaxation* and crosslinking by swelling techniques.

All antirads shown in Table 9 decreased crosslinking in vacuum. Crosslinking was significantly lower in air with no antirad present; i.e., oxygen functioned as an antirad. Some antirads enhance this effect of oxygen.

However, oxygen accelerated scission. In air, all antirads in Table 9 decreased scission to 11–66% of the value

* When rubber is stretched and held at a fixed strain, the stress gradually decreases.

TABLE 5—Polymer-Monomer Radiation Grafting

Polymer	*Monomer and per cent*	*Dose** (*megarad*)	*% Converted monomer in copolymer*	*Type graft*
Poly(methyl methacrylate)	Styrene, 21	1	16.3	Total
Poly(methyl methacrylate)	Styrene, 75	1		Degraded
Poly(2,5-dichlorostyrene)	Styrene, 35	1	20.4	Total
Teflon	Styrene	1.75	4.9	Surface
Polyethylene	Styrene	0.52	10.2	Total

* Room temperature Co^{60} irradiations.

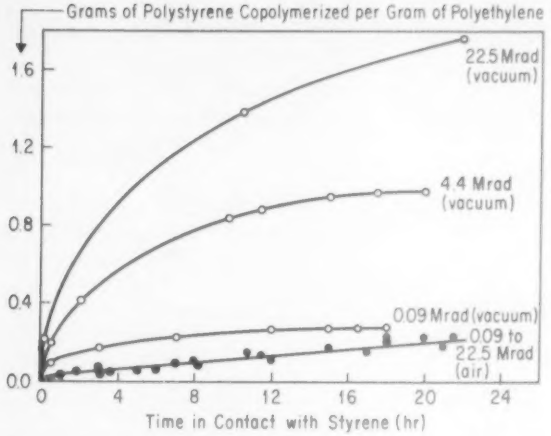


FIG. 2. GRAFT COPOLYMERIZATION of polystyrene and polyethylene (temperature of irradiation, 86° F; temperature of styrene, 72° F; dose rate, 265,000 rads/hr) using preirradiation technique; polyethylene was irradiated then contacted with styrene

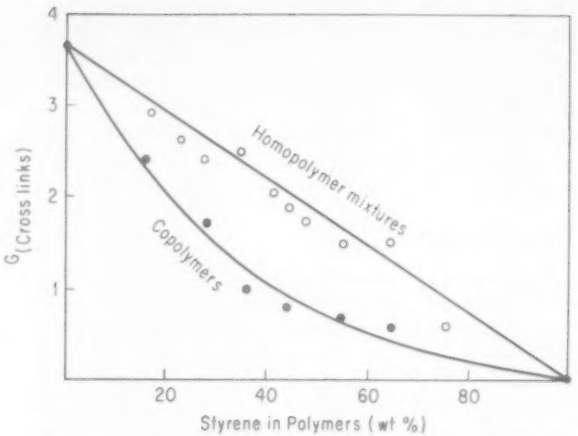


FIG. 3. INCREASED RADIATION RESISTANCE is obtained by increasing aromatic content of styrene-butadiene copolymer. Incorporation of styrene in copolymer molecule is compared with mixtures of the two polymers

for the uninhibited material. Antirads also reduced scission in the absence of air by as much as 50%. Most scissions (90–99%) involve only temporary chain fractures that rapidly recombine.

New Polymers

Antirads sometimes leach out or are otherwise removed from the rubber. Thus, research has been conducted on chemically incorporating antirad groups in the polymers.

Emulsion polybutadiene treated with methyl mercaptan formed adducts involving carbon-carbon double bonds in the original polymer (*59*). In comparison with vulcanizates prepared by normal techniques, the new materials showed increased resistance to gamma radiation as well as good thermal and ozone stability. Some products were more resistant to radiation than natural rubber, particularly at temperatures up to 200° F.

Increasing the aromatic content of the elastomer molecule improves radiation resistance. Thus, silicone elastomers are substantially improved in both radiation and heat stability by the incorporation of phenyl groups (*54*). Also, raising the styrene content of styrene-butadiene copolymers increases resistance to crosslinking (*53, 60*). This was not the same dilution effect noted with physical mixtures of the two polymers but a true protection, as shown in Fig. 3.

Copolymers of ethyl acrylate and maleic anhydride crosslinked with little scission on radiolysis (*53*). Reaction with aromatic amines, e.g., aniline, naphthylamine and aminobiphenyl, yield adducts to the anhydride groups. These adducts showed less crosslinking and more scission than the base polymer. The crosslinking yields decreased with the increasing resonance capability of the substituents. Similarly, poly(*n*-vinylcarbazole), a homopolymer of high resonance energy, protected ethyl acrylate from radiation damage in a copolymer (*53*).

TABLE 6—Radiation Resistance of Elastomers

Material	*Threshold dose for 25% change* (10^6 rads)*
Polyethylene†	90
Polyisoprene (natural rubber)†	25
Styrene-butadiene rubber†	10
Nitrile rubber†	7
Neoprene rubber‡	6
Silicone rubber†	6
Butyl rubber‡	4
Fluoroelastomers‡	4
Acrylate rubber†	3
Polysulfide‡	2

* Based on the most sensitive elastomer property, usually tensile strength.
† Crosslinks predominantly.
‡ Scissions predominantly.

TABLE 7—Effect of Antirads in Natural Rubber

	*Yields**			
	$G_{crosslinks}$		$G_{scissions}$	
Antirad (5 parts/hundred)	*Vacuum*	*Air*	*Nitrogen*	*Air*
No antirad (control)	1.9	0.29	2.7	13
n-Cyclohexyl-*n'*-phenyl-paraphenylenediamine	1.3	0.33	1.2	1.4
6-Phenyl-2,2,4-trimethyl-1,2-dihydroquinoline	0.83	0.9	1.9	4.2
n,n'-Dioctylpara-phenylenediamine	0.87	0.12	1.5	5.0
1,4-Naphthoquinone	1.1	0.48	2.0	5.6
β-Naphthol	1.1	0.24	1.3	4.1

* Gamma irradiation at room temperature.

Vulcanization

Vulcanization of rubber by irradiation continues to be of interest because

1. Irradiation vulcanizates have high resistance to thermal and oxidative aging and to solvents and chemically active media.

2. Vulcanization proceeds without heat.

3. Some products are unique.

Several filled and unfilled rubbers have been given doses of 10^7–10^8 rads (*61*). In contrast to sulfur vulcanizations, the relative rate of stress relaxation depends on the crosslink density in the network of the irradiation vulcanizates. The latter showed a fivefold higher resistance to aging, higher heat resistance, higher endurance to repeated deformation and lower residual deformation.

Some test work was done on vulcanization of elastomer components, e.g., "O"-rings, hoses and gaskets. In general, radiation performance was predictable from the behavior of the basic elastomer in the component. An interesting application is the vulcanization of aircraft and automobile tires (*62*). An uncured tubeless tire having a GR-S* tread and natural-rubber carcass with Dacron cord was gamma-irradiated to 4×10^7 rads in nitrogen. Tests indicated that the vulcanizate aged at least as well as conventionally vulcanized tires and may wear longer and better.

* * *

This article is taken in part from a book being edited by the authors for the AEC Office of Technical Information.

* 78% butadiene and 22% styrene copolymer.

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Combined

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ENVIRONMENTAL CONDITIONS—temperature, surrounding media, stresses—often exert a great influence on what the effects of radiation will be on materials: Some organic materials show sizeable radiation damage only above a certain temperature threshold; changes in properties with irradiation can differ markedly for a material when it is under dynamic stress and when it is stress free; the kind of atmosphere can determine whether or not radiation will enhance corrosion rates. Although we are nowhere near the point where we can make generalizations about the influence of environments on radiation effects for broad classes of materials, a review of the present data does reveal some emergent patterns which we discuss in this article.

Temperature

In metals, the temperature during irradiation determines whether crystal defects will be "locked in" or anneal out; hence, in general, a metal subjected to a certain dose will sustain more damage at a low temperature than at a higher temperature.

In organics, no such generalization is possible; damage is quite sensitive to the physical state and specific molecular properties. However, some conclusions are possible for specific kinds of organics.

In elastomers for instance, radiation and heat produce similar effects. Both higher temperatures and increased radiation exposure generally increase the deterioration of these materials. Dose rate, however, apparently has a negligible effect on permanent radiation effects in elastomers (*1*).

For some of these materials the temperature must exceed a critical value before temperature effects occur. For instance a group of butadiene acrylontrile elastomers were exposed, while under static compression, at temperatures from −65° F to 200° F. Although the compression "set" (or permanent deformation) increased with increasing radiation exposure (*2*), there was no temperature effect within statistical variation of the tests. Apparently the highest temperature investigated was not a critical temperature for these materials; we would expect irradiations at still higher temperatures to accelerate the damage.

Figure 1 shows the effect of heat combined with radiation on seven rubber stocks (*3*). These data, obtained during gamma irradiations in air, represent the time required for a 50% decrease in the tension to occur in a specimen elongated by 80%. The effect of increasing temperature is to accelerate stress relaxation. The continuous stress relaxation is evidence that the change in Young's modulus of rubber under constant elongation is caused solely through breaking of molecular chains.

Workers have tried to determine whether the effects of heat and radiation are synergistic (*3–5*)—i.e., whether the effects of concurrent heat and radiation are greater than a simple summation of the separate effects. Because the separate effects of radiation and heat are similar, there was reason to suspect that the effects would be simply additive. After analyzing the data of Fig. 1, Born (*3*) has concluded that, within experimental error, heat and radiation effects are simply additive for Hycar 1002, natural rubber, Neoprene GN, and GR-S elastomers. On the other hand, data for Neoprene and three silicones, SE-551, SE-371, and SE-750, indicate that heat and radiation effects are synergistic (*4, 5*).

These apparently conflicting findings suggest that there might be a synergistic threshold that depends on both dose rate and temperature.

The performance of organic coolants is gauged by the temperatures they can withstand before decomposing excessively (*6*). Figure 2 shows the change in viscosity for biphenyl as a function of irradiation temperature in the

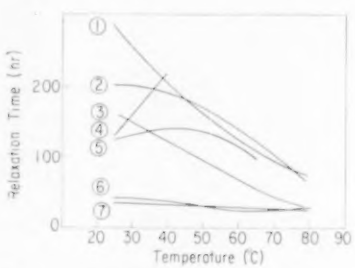

FIG. 1. EFFECT OF TEMPERATURE on relaxation time of rubber exposed to 1.76 × 10^6 rep/hr of gammas in air. Stock name with initial stress (in psi at 25° C): 1—Black GR-S (152.9); 2—Gum Natural (85.7); 3—Black Natural (238.2); 4—Gum GR-S (33.4); 5—Black Hycar 1002 (243.7); 6—Black Neoprene GN (230.0); 7—Gum Neoprene GN (102.1)

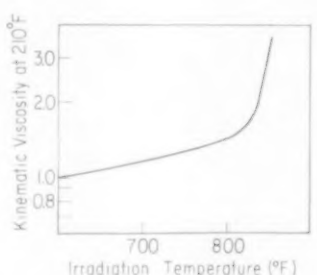

FIG. 2. VISCOSITY CHANGE with temperature (relative to value at 600° F) in critical region for irradiated biphenyl. Dose was approximately 2 × 10^{18} thermal neutrons per cm^2 plus gammas and fast neutrons. Biphenyl was exposed in Brookhaven reactor. Curve indicates excessive decomposition above 800° F point

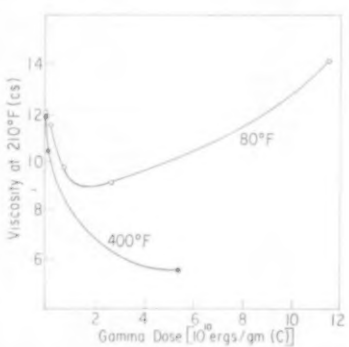

FIG. 3. HYDRAULIC FLUID—effect of temperature on change in viscosity with irradiation dose for Calresearch 216. Irradiation was under helium in sealed stainless-steel capsules in canal source at MTR

Environmental Effects

decomposition threshold region. It is difficult to separate the temperature and radiation effects since measurements do not exist for unirradiated biphenyl over the same temperature cycle (i.e., exposure to 600°–800° F followed by viscosity measurement at 210° F). However, the increase in viscosity of biphenyl over the range of irradiation temperatures from 285° F to 715° F appears independent of temperature below 800° F. Above this threshold, temperature and radiation dose have proved to be synergistic in their effects.

Calresearch 216, a hydraulic fluid, consists of 84% alkyldiphenyl ether-base stock, 14% polybutene and 2% bis (tridecyl) selenide. The combined effects of radiation and temperature on this fluid are shown in Fig. 3. Here the viscosity first decreases because of partial depolymerization of the viscosity-index improver. The subsequent increase in viscosity at the lower temperature follows the crosslinking of main molecular constituents.

Surrounding Medium

Oxidation. In some materials the primary mechanism of radiation damage is an enhanced oxidation. For these materials irradiation in an oxygen-free atmosphere results in less severe property changes. However, despite the fact that both heat and radiation promote oxidation, the best antioxidants are not necessarily effective as antirads (additives that serve to protect materials against radiation). Born's data on a natural-rubber gum stock indicate acceleration of radiation damage to an elastomer in an oxidizing atmosphere.

Investigations also demonstrate the action of oxygen in radiation damage to Teflon (*2*). Irradiation to 10^8–10^{10} ergs/gm(C) in air caused extreme embrittlement and loss of strength; irradiation in Oronite 8515 fluid, which restricts oxygen contact and thereby reduces oxygen uptake, showed less damage. A surface-to-volume-ratio effect has also been observed—the lower surface-to-volume ratios of thick specimens reduce oxygen contact with the polymer (*8*). This dependence on specimen geometry makes comparison of data from various laboratories difficult, and tends to make engineering evaluation of certain data unduly pessimistic.

Ozone can cause surface cracking in elastomers under stress. This is accelerated under irradiation in air since radiation increases the ozone concentration. "Ozone-resistant" materials such as silicones and chlorosulfonated polyethylene show much less damage (*1*).

Elastomeric materials find applications both as adhesives and sealants. Morgan (*9*) has reported results on three sealant materials subjected to reactor radiation while immersed in air and in JP-4 fuel (MIL-F-5624). His results are shown in Fig. 4. In all three cases the tensile strengths of sealants irradiated in fuel dropped to about 20% of the initial values after an exposure of 10^9 ergs/gm(C) of reactor gammas and associated neutrons. The sealants irradiated in air, however, *increased* in tensile strength, with the exception of one in which tensile strength decreased to 80% of the initial value.

Static and Dynamic Irradiation of Nitrile Silicone

Condition during irradiation	*Postirradiation deflection (lb./in.)*		*Increase (%)*
	Control	*Irradiated**	
Uncompressed	1,307	2,000	53
Compressed	1,250	1,470	18
Dynamic†	1,333	1,627	22

* Exposure: gamma—4×10^8 ergs/gm(C); neutron ($E > 0.33$ Mev)—2×10^{14} n/cm²

† 60 cpm 0.07-in. compression from original thickness to 0.445 in.

The increased damage of the specimens in fuel is attributed to:

- steric effects from swelling of the elastomer, which pushes apart the polymer chains
- reactions between fuel molecules and free radicals formed during irradiation
- neutralization of free radicals to prevent crosslinking or recombination of polymer bonds
- and graft polymerization reactions between the fuel and the polymer.

Corrosion. The surrounding medium asserts itself in the corrosion of metals, but in a way that is difficult to evaluate. More in line with the normal way of looking at corrosion, one might better consider the effect of radiation on corrosion, rather than the effect of the medium on radiation-induced corrosion. Out of the many types of corrosion and the varying effects of corrosive media, we will only briefly indicate a few of the observed effects.

Aluminum-nickel alloys tested by Argonne National Laboratory in a demineralized-water loop in the MTR (*10*), corroded less when irradiated than when unirradiated. Rate of corrosive weight loss and radiation flux density were inversely related.

For 1100 aluminum alloy in Hanford process water (*11*), on the other hand, corrosion rate increases exponentially with thermal-neutron flux, with a rate constant of about 2×10^{-13} $(nv)^{-1}$. Radiation, however, may not be the independent variable even here, because of other conditions, such as temperature and water composition, that may prevail.

Exposure of 2024-T aluminum, copper and 1020 mild steel to corrosive solution in $2.5 \times 10^5 - 3.0 \times 10^5$-r/hr fields of Co^{60} gammas revealed both protective and nonprotective action by the radiation, depending on the conditions. Where corrosion inhibition depends on formation of a protective oxide surface film, radiation exerts a protective effect by making the fluid more oxidizing. Where no protective film is formed in a normally rapid corrosive system, radiation accelerates corrosion, probably because the radiation-induced decomposition of

the corrosive solution increases depolarization effects (*12*).

From data such as these, we can conclude that at most there is little direct evidence to indicate that radiation significantly increases the corrosion rates of most metals.

Dynamic Stress

Experience shows that "working" of materials during irradiation can have important effects.

For example, a lubricating oil (MIL-L-7808) was irradiated statically in a sealed container, and also while it was being used to lubricate a jet-engine gear box (*13*). The static sample withstood an exposure five times greater than the dynamic sample, with only slight change in viscosity, whereas the worked fluid suffered a severe decrease that rendered it useless as a lubricant. Others have reported similar results (*14, 15*).

Fritz's comprehensive study of the combined effects of radiation and dynamic stresses (*16*) predicts increased damage in hydrodynamic systems. Bubbles formed by turbulent flow affect the gas-liquid reaction rates of the radiolytic products; intense acoustic fields can degrade liquid polymers producing effects that should add to the radiation effects.

In solid polymers that give off gases upon exposure to radiation the threshold dose for bubble formation should be lower in the presence of intense dynamic stress fields since these fields enhance diffusion of gas molecules (*16*). At interfaces of acoustically heterogeneous materials this decrease in threshold may be particularly noticeable. Thus, organic adhesive bonds should be more susceptible to damage under dynamic stress.

Another ramification of the dynamic stress condition in solids is the heating it produces, which increases the reaction rates by about a factor of two for each 10° C rise.

Because dynamic mechanical stresses change molecular orientation, the effects of orientation need to be considered. Apparently, in a highly oriented state polymer chains are aligned close enough together over long enough distances to increase the probability of crosslinking. This effect is illustrated by the differences between Born's results of irradiation of the natural rubber gum stock in stressed and unstressed conditions.

In recent work Morgan (*9*) subjected specimens of a nitrile silicone to cyclic compression during irradiation. For comparison, he irradiated uncompressed and compressed static specimens and he tested unirradiated controls compressed and uncompressed. The table shows postirradiation load-deflection data. From these data we observe that the cyclic compression results in postirradiation properties that are intermediate to those of the static compressed and uncompressed specimens. The most drastic radiation effect was in the uncompressed specimens.

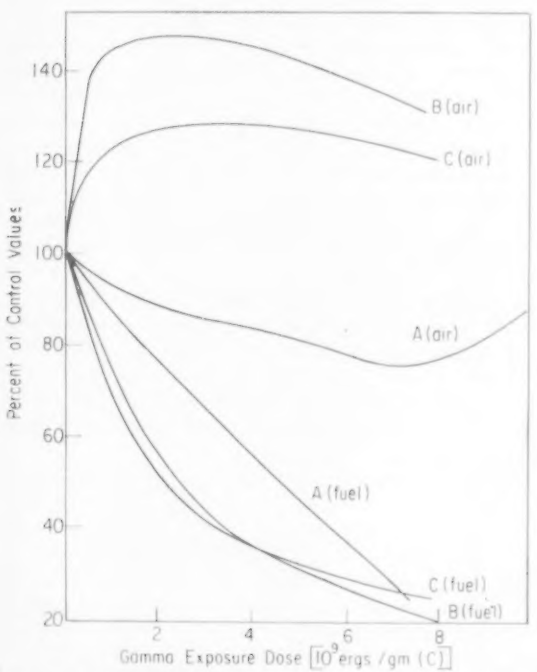

FIG. 4. TENSILE STRENGTH of sealant materials vs. radiation dose shows marked difference between fuel and air environment

Postirradiation Changes

Although the designer would prefer to collect his data during irradiation, he usually ends up getting most of his data from postirradiation measurements. This practice leads to pitfalls for the unwary.

As an example, at Convair we measured the values of ultimate strength, relative to the control values, for neoprene rubber specimens at postirradiation periods up to 35 days. The specimens irradiated, stored and tested at approximately 75° F continuously decreased in strength than those at the start of storage. When specimens were stored at −20° F for corresponding postirradiation periods, no statistically significant changes were seen (*17*).

What the results might have been if, after storage at −20° F, the specimens had been stored for a while at room temperature, we can only conjecture. However, it seems reasonable to assume that the chemical reactions that continue after irradiation between the radiation-induced intermediates are merely retarded by the low temperature, and will eventually approach the same equilibrium condition as at the higher temperature.

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Niobium—Promising High-Temperature Reactor-Core Material

Among refractory metals, niobium stands out for reactor use at over 1,600° F. It offers—along with low capture cross section—high-strength alloys, fabricability and stability in nonoxidizing environments

By J. A. DeMASTRY and R. F. DICKERSON, *Battelle Memorial Institute, Columbus, Ohio*

As operating temperatures for projected reactors climb higher and higher, niobium assumes greater interest for the reactor metallurgist. The properties of the niobium-base alloys strongly suggest applications in pressurized-water, high-temperature inert-gas-cooled and sodium-cooled reactors and superheater cores. Current work also indicates that niobium-base, enriched-uranium alloys may be valuable as fuels for use at 1,600°–2,000° F in a nonoxidizing environment.

Although the technology of these materials has advanced rapidly in recent months, their use is not definitely planned for any current reactor. Several areas of Nb technology require additional research and development. The more important of these include improved oxidation resistance, increased high-temperature strength by alloying, improved methods of fabricating the high-strength alloys and reduced material costs. However, with full realization of the problem areas, it seems reasonable to predict that, within a few years, Nb will be one of the important reactor materials.

The two properties most needed in reactor structural materials are high-temperature strength and reasonably low thermal-neutron-absorption cross section. Zirconium and zirconium alloys are excellent in a nonoxidizing atmosphere and if temperatures do not exceed 932° F (500° C). Temporary high temperatures resulting from power surges can be a problem, however. If the neutron cross section is not critical, austenitic stainless steels, iron-chromium-aluminum alloys, nickel-chromium alloys and super alloys of the Hastelloy type provide enough strength and corrosion resistance in several coolants to be useful up to about 1,800° F. Above this temperature, the reactor metallurgist must look to molybdenum, tungsten, tantalum, vanadium or niobium.

On the basis of strength alone, any of the latter so-called refractory metals would be a logical choice. Niobium, however, possesses the best combination of properties (Table 1):

1. Stronger at high temperatures than vanadium and tantalum.
2. Lowest thermal-neutron-capture cross section of the refractory group.
3. Readily sintered, forged, swaged, rolled, machined and welded.
4. Low rate of work hardening.
5. Reasonably compatible with most uranium-base fuel materials.
6. Not attacked by inert gases or most molten metals. (*Cont. on p. 88*)

TABLE 1—Capture Cross Sections (*1*), High-Temperature Strengths

Material	*Tensile strength*		*Cross section (barns)*
	Temp. (°F)	*10^3 psi*	
Zirconium	900	9.6	0.180
Zircaloy-2	900	~33	0.195
Aluminum (1100)	500	3.5	0.230
Niobium	1,500	21	1.15
Molybdenum	1,500	~35	2.7
Iron	1,300	9.2	2.53
Chromium	1,550	18	3.1
"A" Nickel	1,400	14	4.8
Vanadium	1,600	~15	4.98
Titanium	1,000	~20	5.8
Tungsten	1,500	~110	19.2
Tantalum	1,500	29	21.0
Cobalt	1,700	12	37.0

TABLE 2—Properties of Unalloyed Niobium

Property	*Value*	*Ref.*
Atomic number	41	*2*
Atomic weight	92.91	*2*
Isotope, natural	93	*3*
Isotopes, artificial	89–99	*3*
Atomic volume (cm^3/gm-atom)	10.83	*4*
Lattice structure	Body-centered cubic	*5*
Lattice constant (Å)	3.294	*5*
Thermal-neutron cross section (b)	1.15	*6*
Positive-ion emission (ev)	5.52	*7*
Density (gm/cm^3)	8.57	*8*
Melting point (°F)	4,380° F	*9*
Boiling point (°F)	9,260° F	*10*
Thermal conductivity (cal/sec/cm/°C)	0.125	*11*
Coefficient of linear thermal expansion ($°C^{-1}$)	7.1×10^{-6}	*8*
Electrical resistivity, 20° C (microhm-cm)	13.2	*12*
Electrical conductivity (% IACS)	13.3	*4*
Transition temperature (°K)	8.0°–8.3	*13*

TABLE 3—Effect of Cold Work on Nb Hardness

Reduction by cold rolling (%)	*Vickers Hardness of Nb from various melting stocks*		
	Powder (31)	*Powder* (32)	*Electron-beam melted* (4)
0	88.3	95	54
10	125		
20	132	144	91
30	140		
50	156	151	112
60	160	164	130
70	163		
80	166	167	145
90	169	179	154

Unalloyed Properties

A brief study of the properties listed in Table 2 indicates more specifically the reasons for interest in niobium.

The lattice spacing of 3.294 Å can be compared to the Goldschmidt atomic diameter of 2.94 Å. Since the zone of favorable size factor for possible solid-solution formation extends from 2.50 to 3.38 Å, one could expect a fairly large number of solid-solution alloys. The thermal-neutron-absorption cross section and the thermal conductivity are reasonable. The high melting point indicates good strength at elevated temperature, and the electrical properties make the metal amenable to arc-melting.

Potential of Alloying

Proper alloying will greatly improve the properties of niobium. As we show later in this article, elevated-temperature strengths can be increased substantially, and hot-water-corrosion resistance can be improved to a point where it is almost equal to that of zircaloy-2.

Since solid-solution alloying is one method of improving strengths, it is fortunate that a large number of elements form solid solutions with niobium—among the most interesting are zirconium, titanium, vanadium, tantalum and molybdenum. A large number of binary, ternary and quaternary alloys should provide desirable properties. On the other hand, precipitation hardening can also produce good elevated-temperature-strength properties. In the niobium-chromium system, there is about 23% solid solubility of chromium in niobium at 3,092° F. This decreases to about 6% at room temperature. These conditions result in an alloying system that can be strengthened by both solid-solution effects and age-hardening.

Production and alloy preparation. Niobium occurs closely associated with tantalum in nature and must be separated for reactor applications.

One of the most-used methods of separation from columbite ore is by fusion with a molten caustic (*14*), which ultimately produces Nb_2O_5. The pentoxide is reduced to the metal with carbon during vacuum sintering. This sintered product can be melted in a variety of ways to produce purer metal or alloys. Ultrahigh-purity niobium can be produced by cage-zone induction melting (*15*) or by electron-beam melting (*16*). Vanadium, iron, aluminum, nickel and chromium evaporate to only a few parts per million, and oxygen and carbon are readily removed.

Alloying is accomplished satisfactorily without impurity pickup by the consumable-electrode arc-melting technique. Five-hundred-pound ingots have been produced by this technique (*17*).

Fabrication. Unalloyed niobium can be worked to a considerable degree before it work-hardens appreciably (*18*). Table 3 gives examples of the increase in hardness due to cold working; although the initial increase is large, the rate of increase decreases with heavier reductions. Annealing at 2,372° F for 1 hr in a vacuum of 10^{-5} mm of Hg results in a completely recrystallized structure; recrystallization occurs as low as 1,922° F.

The fabrication of niobium-base alloys is not quite so straight-forward—as the alloy strength increases, the ease of fabrication decreases. The principal problem is still the initial breakdown of the cast structure, which can be accomplished by forging or extruding at elevated temperatures (*19*). After breakdown, the alloys can usually be warm- or cold-rolled. Both rods and tubes have been successfully produced by extrusion (*17*).

No particular difficulties are encountered in machining niobium and its alloys if machining practices for stainless steel are followed. Ductile arc welds are satisfactory if the molten weld pool and hot metal are protected from contamination. It is standard practice to resistance-weld stock that is less than 0.02 in. thick.

Gas-pressure-bonding techniques are suitable for joining Nb. Bonding is accomplished at a relatively low temperature (1,550°–1,650° F) under a helium pressure of 10,000 psi with zirconium at the interface to promote bonding. Direct self-bonding of Nb has been accomplished by pressure-bonding at 2,100° F and 10,000 psi for 3 hr. Ductile bonds are produced in both cases. Although no attempts have been made to bond Nb and Nb-U fuels, no difficulties are expected.

Physical properties. Thermal-conductivity measurements have been made on unalloyed niobium (Table 4). Information on the effects of alloying on thermal conductivity is currently very sparce. It is expected that thermal conductivity follows the solidus curve in the case of solid-solution alloys and, therefore, decreases from the value for unalloyed niobium to a minimum as the solidus curve decreases. This decrease should not be a serious factor.

The effect of alloying on room-temperature electrical resistivity is not

TABLE 4—Thermal Conductivity of Unalloyed Niobium (*20*)*

Temperature (°C)	*Thermal conductivity (gm-cal/cm/sec/°C)*
93	0.110
251	0.115
528	0.123
688	0.131
884	0.138
1,104	0.146
1,346	0.152
1,639	0.163

* Converted from BTU/hr/ft/°F.

TABLE 5—Electrical Resistivity of Annealed Alloys (*19*)

Nb purity (%)	*Additive (%)*	*Resistivity at 20° C (microhm-cm)*
99.95		16.25
	5 Mo	16.97
	10 Mo	17.6
	5 W	17.2
	10 W	21.1
	1 Zr	15.82
	2 Zr	17.53
	2 Ti	18.86
99.98		14.8
	7.6 Mo	16.2
	9.4 Mo	16.75
	1.6 V	16.0
	3.1 V	17.4
	4.6 V	18.6
	2.0 Al	19.4

great. This is indicated by the measurements given in Table 5 obtained from some typical binary alloys.

Mechanical properties. The hardness of unalloyed niobium varies greatly with oxygen content. Extremely pure niobium has a hardness below 100 DPH, whereas niobium containing 700 ppm oxygen is on the order of 250 DPH. As would be expected, alloying increases the hardness markedly, which is illustrated in Fig. 1. As indicated by Fig. 2 (*22*), niobium alloys retain their

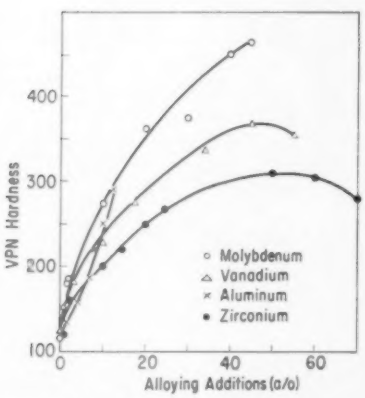


FIG. 1. ALLOYING increases room-temperature hardness of niobium

TABLE 6—Tensile Properties of Niobium Alloys

Composition (w/o)	*Temperature (°F)*	*Tensile strength (psi)*	*Yield strength (psi)*	*Elongation (%)*	*Ref.*
Pure Nb	Room temp.	29,480		32.6	*25*
Production Nb	Room temp.	48,620		19.2	*25*
	932	48,400		9.6	*25*
99.9% Nb	1,500	21,000	16,000	18.0	*29*
3.2 Ti	1,500	17,000	14,000	11.0	*29*
10 Ti	2,200	16,000		18–32	*26*
15 Ti	2,200	12,000		23–33	*26*
1.6 V	68	64,920		19	*21*
	932	35,860		12.8	*21*
	1,500	28,500	16,500	30	*29*
5 V	77	86,150	74,400	27.2	*24*
	80	86,000	74,000		*27*
	2,000	36,900	33,500	37.4	*24*
	2,000	37,000	34,000		*27*
10.5 V	68	67,320		21.1	*25*
	932	55,880		5.9	*25*
1 W	80	48,000	44,000		*27*
	2,000	12,000	11,000		*27*
5 W	68	43,780		8.9	*21*
	2,000	14,000	12,000		*27*
10 W	68	65,340		9.9	*21*
0.7 Zr	80	50,000	35,000		*27*
	930	30,000	15,000		*27*
	2,200	14,800		16	*27*
4.33 Zr	1,200	82,400		4	*19*
	1,470	76,400	69,000		*19*
1 Mo	77	52,850	43,840	26.3	*24*
5 Mo (99.95% Nb)	68	59,400		16.8	*21*
7.8 Mo	Room temp.	60,500		21.9	*25*
	932	38,060		9.7	*25*
9.4 Mo	68	67,540		24.0	*21*
	932	46,420		6.0	*21*
5 Hf	77	69,500	52,500	30.2	*24*
	2,000	46,540	46,500	11.2	*24*
2.0 Al	68	38,060		28.0	*21*
	932	36,740		12.2	*21*
1.84 Cr	1,200	115,000	107,000	4	*19*
	1,470	81,600	68,700	14	*19*
0.5 Ti–0.5 Zr	2,000	26,000		22	*27*
5 Ti–10 Zr	1,500	37,000	34,000	2	*29*
10 Ti–10 Mo	80	100,000	92,000		*28*
	2,000 (air)	35,000			*28*
	2,600 (air)	10,000			*28*
20.5 Ti–4.28 Cr	1,200	92,200	75,500	11	*19*
	1,470	39,700	30,800	40	*19*
5 Mo–5 Hf	77	113,200	100,100	16.6	*24*
2.5 V–2.5 Zr	1,500	38,000		1	*29*
4 V–2.3 Zr	1,500	46,000	30,000	9	*29*
2.2 V–0.54 Fe	1,500	43,000	25,000	31	*29*
1 Ti-1 Zr-1 Hf	2,000	44,000		10	*27*
3 Ti-2 Zr-2 Hf	77	79,500	61,950	30.15	*24*
	2,000	41,800	41,700	1.9	*24*
Fansteel 80	75	47,000			*23*
Fansteel 82	75	55,000			*23*
33 Ta–0.7 Zr	2,000 (air)	29,600			*23*
	2,400 (air)	11,700			*23*

room-temperature hardness at elevated temperatures.

The tensile strength of unalloyed niobium is not particularly high at room temperature, but, like its hardness, niobium retains its strength as temperature increases (Fig. 3). A large number of alloying additions have been made to niobium to improve the elevated-temperature strength. The effects of this alloying are shown in Table 6, which lists typical alloys and

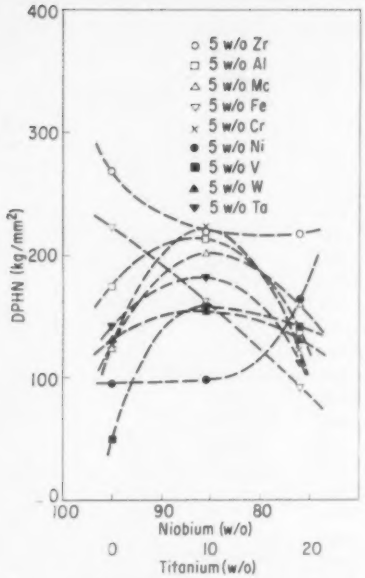


FIG. 2. BINARY AND TERNARY ALLOYS retain hardness at 1,600° F

TABLE 7—Rupture Properties of Nb and Alloys

Composition (w/o)	*Temp. (°F)*	*Stress to produce rupture (psi)* 10 hr	100 hr	500 hr	*Remarks*
Nb (electron beam melted)	1,600		8,000		
	1,800		6,500		
	1,650	10,500	10,000		
	1,800	9,000	8,500		
	2,000	5,500	5,000		
	2,200	5,000	4,000		
Nb (powder)	1,800	22,500	17,000		Cold-rolled
	1,800	16,000	15,000		Recrystallized
	1,600		35,000		Contained 0.65 w/o Zr
	1,800		30,000		Contained 0.65 w/o Zr
F 48*	2,000		35,000		
	2,200		17,000		
F 50†	2,000		20,000		
	2,200		11,000		
Nb–0.7 Zr (Fansteel 80)	2,000		18,800	11,000	In argon
Nb–33 Ta–0.7 Zr (Fansteel 82)	2,000		17,500	13,500	In argon
Nb–10 Ti	1,800	15,000	12,500		
Nb–10 Ti–2.5 W	1,800	20,000			

* Nb-15 W-5 Mo-1 Zr-0.04 C-0.04 O_2-0.05 N_2 (GE alloy).
† Nb-15 W-5 Mo-1 Zr-0.04 C-0.04 O_2-0.05 N_2-3.5 to 5.0 Ti (GE alloy).

results based on a complete survey of the unclassified literature. Hafnium, chromium, zirconium and tungsten seem to be the most potent alloying additions.

The brittle-ductile transition temperature appears to lie between −150° F and −320° F for high-purity material and is relatively unaffected by interstitial levels.

The creep properties of unalloyed Fansteel triple-sintered niobium are shown in Fig. 4 (*30*). Creep data for niobium alloys (Table 7) are scarce, but the data available and estimates based on Larson-Miller parameters indicate that alloying should improve creep strength.

Compatibility. A major failing of niobium is its inability to withstand oxidation at even moderately high temperatures. Alloying improves the oxidation resistance in all cases but not enough to allow use in oxidizing atmospheres (*31*).

Niobium is not attacked severely by water at 600° F—high-purity material has a weight gain of 0.73 mg/cm² after 224 days. Alloying improves this corrosion life (*32*). As an example, a niobium-12.6 a/o vanadium alloy shows a weight gain of 0.32 mg/cm² for the same period. In 680° F water, commercial grade does not perform well, whereas some alloys exhibit corrosion resistance comparable with that of zircaloy-2 (Table 8).

Below 1,832° F, niobium should not be attacked by high-purity sodium or NaK. Although there are no direct data on the compatibility of niobium with helium and argon, there is much indirect evidence that indicates no effect from high-purity gas. High-temperature heat treatments, stress-rupture tests and, of course, arc melting have been performed in atmospheres of both gases without causing impurity pickup.

(*Continued on page 132*)

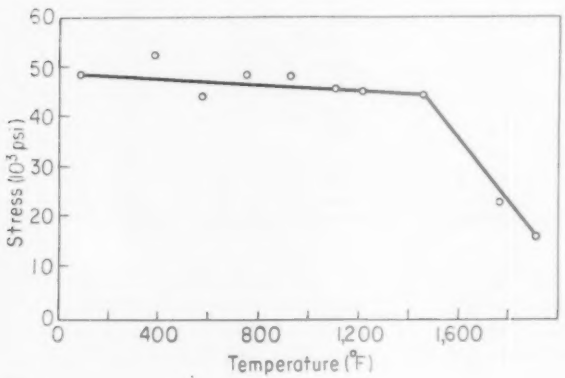
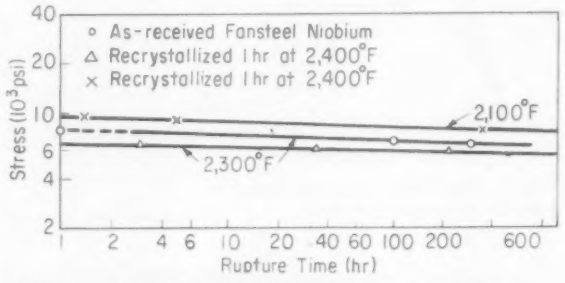
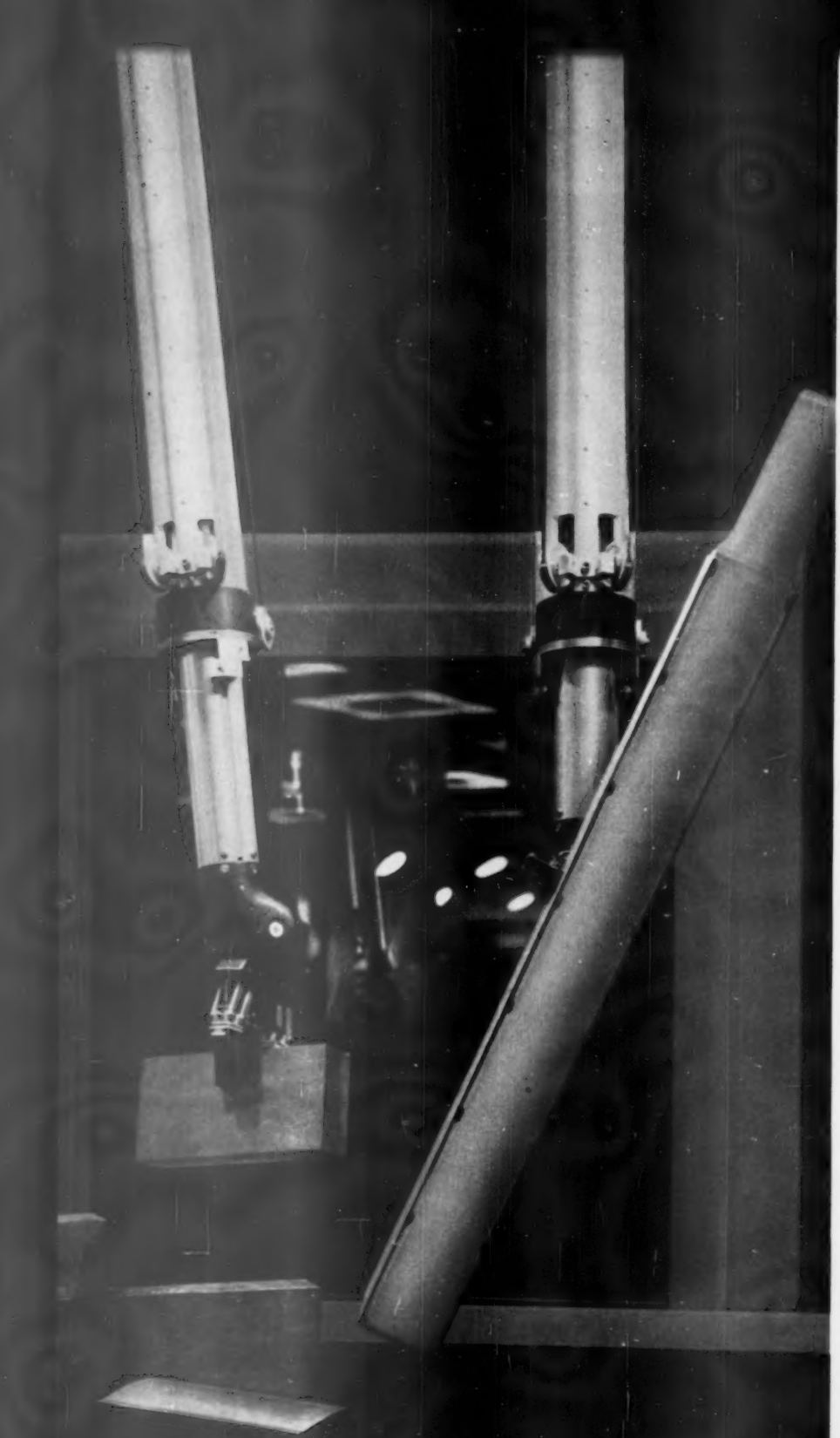


FIG. 3. ULTIMATE TENSILE STRENGTH of unalloyed niobium



↑ FIG. 4. CREEP AND CREEP RUPTURE of unalloyed Nb



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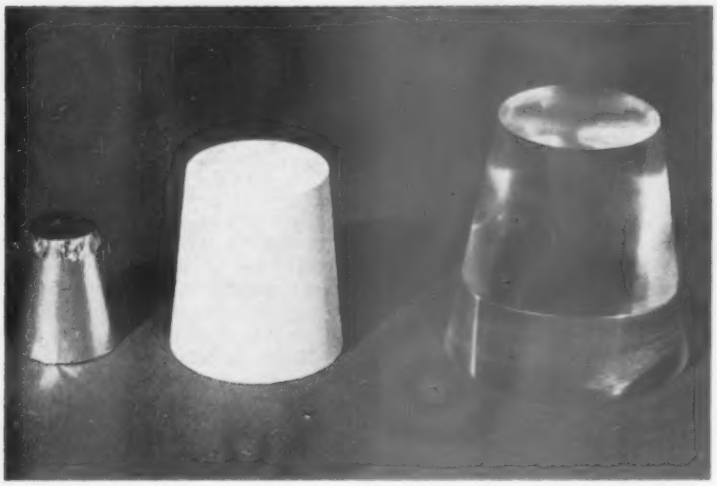

FIG. 1. CONICAL SCINTILLATORS of proper size, reflected with aluminum foil (left) or aluminum oxide (center) produce total-absorption pulses with low-energy photons. (Optical illusion makes phosphor at right seem to be in two sections)

Conical Plastic Scintillators Show Total Gamma Absorption

By GERALD J. HINE and JOHN A. CARDARELLI
Veterans Administration Hospital and Boston University School of Medicine, Boston, Massachusetts

For special applications as radiation detectors plastic scintillators have some properties that make them superior to sodium-iodide crystals. But the inability to demonstrate total absorption of gamma photons (scintillation pulses corresponding to the full energy of incident photons) in plastic scintillators has appeared as a serious deficiency in our assessment of their basic properties. Total gamma-ray absorption is needed for energy calibration and discrimination against background radiation in detection of monoenergetic photons.

We have recently demonstrated that one can observe total photon absorption, at least with low-energy X- and gamma rays. Our best results have been with lead-loaded, conically shaped scintillators surrounded by aluminum oxide as a reflector of light (Fig. 1).

Why Plastic Scintillators?

Outstanding among the advantages of plastic detectors are these:

Decay times of light pulses are several hundred times shorter in plastics than in sodium iodide. This is important for coincidence measurements and very large counting rates.

Machining of plastics to any size or shape is possible without permanent enclosure in an air-tight container.

Air-equivalent response can be had from a plastic over a wide photon-energy range. Thus plastic scintillators are appropriate for dosimetry.

Large sizes (as big as 16 in. in diameter) are available from several manufacturers at moderate cost. This is useful for counting extended sources like the human body (*1*), low-activity samples (*2*) or background.

Absence of total-absorption pulses when gamma rays are incident on plastic scintillators can be traced to two fundamental difficulties. First, photoelectric absorption in plastic scintillators is very small compared, for example, with that in sodium iodide. The latter has a high-atomic-number constitutent in iodine ($Z = 53$), whereas the average atomic number in plastics is ~ 6. Second, we have demonstrated that a major difficulty exists in collecting the light produced by gamma-ray absorption in plastic scintillators. The fraction of the light that leaves the scintillator and enters the photomultiplier depends on size and shape of the scintillator.

Increasing scintillator dimensions enhances total gamma-ray absorption by increasing multiple Compton interactions. At the same time light losses increase and defeat the advantage. The same difficulty is experienced when the plastic scintillator is loaded with heavy elements to increase photoelectric absorption.

Light Collection

Experiments with monoenergetic electrons demonstrate the difficulties of light collection (*3*). For example, Fig. 2 shows our results from measuring 624-kev internal-conversion electrons of a thin Cs^{137} source with square and round cylindrical scintillators of different sizes. As thickness increases, resolution becomes worse; pulse height becomes smaller, and counting rate in the valley between the conversion-electron

Kodak reports on:

apathy in Pittsburgh . . . sooty things with a lot of physics in them . . . little white specks that move . . . a little literature before the 11 o'clock news

A shining trap for Mg

When we read the advance program for this year's Pittsburgh Conference on Analytical Chemistry & Applied Spectroscopy, we decided on a coup.

One of the papers was to state an interesting fact about bissalicylideneethylenediamine. This compound, in slightly alkaline *N,N-Dimethylformamide* (Eastman 5870), chelates Mg ions, and thereby becomes highly fluorescent. The excitation maximum occurs at 355mμ, and the emission maximum at 439mμ. A sensitivity of 7×10^{-5} micromole of Mg per ml was mentioned.

This time, said we to ourselves, when they come charging out of the meeting room to our exhibit to ask whether we have this reagent, they will encounter no mere bland smile. We will be able to reply, "Yes, sir, here it is, labeled *α,α'-(Ethylenedinitrilo)di-o-cresol* and designated Eastman 8019."

And that is exactly what we were in a position to do that day. The only trouble was that while many people did flock to our booth and talked of many things, not one soul as much as mentioned bissalicylideneethylenediamine.

Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company) has some 3800 other Eastman Organic Chemicals. Many of them do excite a decent level of interest.

A boundary for the infrared

These sooty things have a lot of physics in them. The physics is of the old-fashioned type, not very clear, but not nearly so opaque as the little wonders themselves look when held to the light. Yet they transmit to 30μ in the very far infrared. Their utility lies in the easy adjustability of the spectral position of the transition from opacity to clarity. The opacity is achieved not by absorption and not by interference but by marvelously selective and effective scattering. What interference there is, in fact, operates on the side of clarity by beating down Fresnel reflection losses.

These *Kodak Far Infrared Filters* have turned into a hotter item than we dared hope when we first taught ourselves how to take silver chloride and convert its surface to silver sulfide in a manner as tunable as a fiddle string. Now the infrared trade—military and analytical—has grown to where it needs cut-on filters worse than it needed them ever before. And we are ready—even with a warning that these filters require precautions to protect them from harsh military environments and that silver chloride in the presence of water vapor still corrodes metal just as it always has. Of course, they can be mounted in plastic. The corrosion we can forestall if, at the expense of inserting a few absorption bands, we can be permitted to overcoat with polystyrene.

The pitch for the business is made by a collection of mimeographed sheets entitled "Kodak Far Infrared Filters," obtainable from Eastman Kodak Company, Special Products Sales, Rochester 4, N. Y. Here are given sizes, prices, and the code for specifying the cut-on wavelength wherever wanted from 1 to 5μ.

A tip for radiographers

Little white specks have been appearing on radiographs of zirconium alloys. Since one of the principal reasons for radiographing zirconium alloys in the first place is for detection of tiny tungsten inclusions, this is not surprising. What has surprised the radiographers has been that most of the little white specks appear in different places on two successive films of the same part! Or even on two films made of the same part simultaneously!

Upon investigation* it turns out that the phenomenon does not contain enough high science to be worth the exclamation points. The moving specks are dandruff, cigarette ashes, lint, and such rubbish. So help us!

The junk gets picked up when the customer loads the film into the cardboard exposure holders. These often contain lead foils between which the film nestles. Besides serving as a filter to modify radiation quality, the lead emits electrons to intensify the image density. The junk simply casts electron shadows.

So we published a little paper in *Nondestructive Testing*. We said that in this specialized type of radiography for small inclusions it might be well to put cardboard under the front lead screen and use the lead only as a filter. We also advised surgical cleanliness, a darkroom under slight positive air pressure, and no smoking. This supplementary advice isn't really necessary if you don't try to shave exposure time by putting the lead in contact with the film, but it sounds wholesome. Furthermore, this line of thought led to the question of why make the radiographer load the film into a cardboard exposure holder in his own darkroom. Why not do it for him in our surgically clean, slight-positive-air-pressure, no-smoking factory?

We couldn't think of a good reason why not.

Kodak Industrial X-ray Film, Type M (*the maximum resolution type*) *is now available from x-ray dealers in a* Ready Pack *form, enclosed in individual, disposable, light-tight packets.*

*We needn't have investigated. We could have just dropped off the film, scooped up our money, and run, tarrying only long enough to suggest that 1) two films be routinely made of every part and then compared to distinguish moving white specks from real white specks; and 2) somebody should do a Ph.D. thesis on the effect. Sales would have doubled.

A primer for metallography

You would think we had nothing better to do than write letters and be friendly, helpful, and cheerful.

Though this policy hasn't sunk us yet, we do go through motions to put the dispensing of technical photographic wisdom on a slightly self-sustaining basis. For those who have not yet delved deep enough to frame specific questions, we publish what we call *Kodak Data Books* and print on the cover a small cash price, like 50¢.

Just issued is a new one, "Photomicrography of Metals." It contains 13 pages on the metallographic microscope (unbiased toward any particular make of instrument, since we are not in that business), 3 pages on illumination, 5 on filters, 3 on photographic materials (which we do make), 5 on exposure determination, and 8 on processing and printing—just enough for thoughtful perusal between the evening paper and the 11 o'clock news. The pages are meaty; the illustrations are there to explain, not just fill space; the author (anonymous) is a photomicrographer, not an ad-writing hack.

Theoretically the purchase of these data books from your Kodak dealer draws him and you closer together. Those willing to forego the personal touch can obtain them from Special Sensitized Products Division, Eastman Kodak Company, Rochester 4, N. Y., which is also the place to address specific questions.

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This article starts on page 92

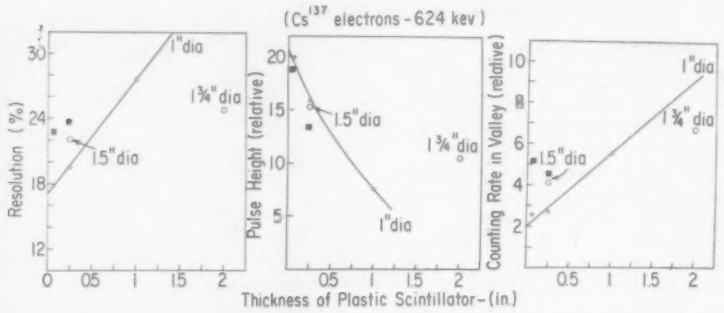


FIG. 2. ELECTRON MEASUREMENTS with square (solid points) and round plastic scintillators show difficulty of light collection. As thickness increases, resolution becomes worse (left), pulse height becomes smaller (center) and counting rate in valley between conversion-electron peak and continuous beta-ray spectrum becomes greater (right)

peak and the continuous spectrum becomes greater. Similar effects are apparent as shape and diameter change. These results are in contrast with those shown by sodium iodide crystals, for which resolution is essentially independent of crystal size.

The loss of pulse height and worsening of resolution that appear in Fig. 2 can be caused only by absorption of fluorescent light produced in the top layer of the scintillator by beta rays. We assume that a large fraction of the light is trapped in the plastic scintillator; this fraction is greater in square pieces than in round ones of equal thickness.

Reflector. The fraction of the light that can escape depends on diameter and thickness in a complex way. We have observed only small differences in comparing good light reflectors. In general, aluminum foil in close contact with all surfaces yields good results; surrounding the scintillator with aluminum oxide instead of foil increases the pulse height slightly. From this study of reflectors we conclude that most of the light lost in the larger scintillators is trapped by multiple internal reflections.

Shape. We found that the light output could be somewhat increased by changing the shape of a plastic scintillator from a cylinder to a truncated cone. Figure 3 shows what happens when a 1.75-in.-diameter, 2-in.-high cylinder is made into a 10-deg cone. Pulse height of the Cs^{137} electron line increases by more than 60%; resolution improves from 24% to 19.5%. By comparing Fig. 2 and Fig. 3 you can see that the 2-in.-high cone delivers almost as much of its light as a $\frac{1}{16}$-in. disk.

We find it difficult to choose the best angle for a cone of given thickness. When thickness is 2 in., a 2-deg cone performs like a cylinder, and a 4-deg cone gives improved light output much as does the 10-deg cone of Fig. 3. There is less improvement in changing a 4-in.-diameter, 4-in.-high cylinder to a 5-deg or 10-deg cone than there is with the 2 × 2-in. cylinder.

Photopeaks

To observe a peak that corresponds to monoenergetic photons one must simultaneously achieve total absorption (photoelectric absorption or multiple Compton collisions) and effective light collection. We have managed to demonstrate such peaks by (a) limiting our observations to low-energy photons, (b) choosing scintillators of appropriate sizes to improve the absorption-to-light-loss ratio and (c) using cones to improve light collection. Some improvement is also available from loading the plastic with a small amount of lead. Figs. 4–6 demonstrate our photon peaks achieved in these ways.

Absorption. That small-energy photons are more likely to produce

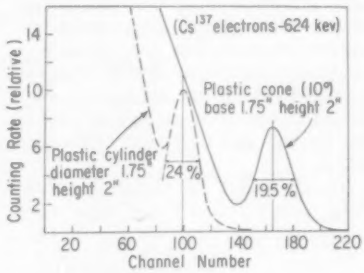
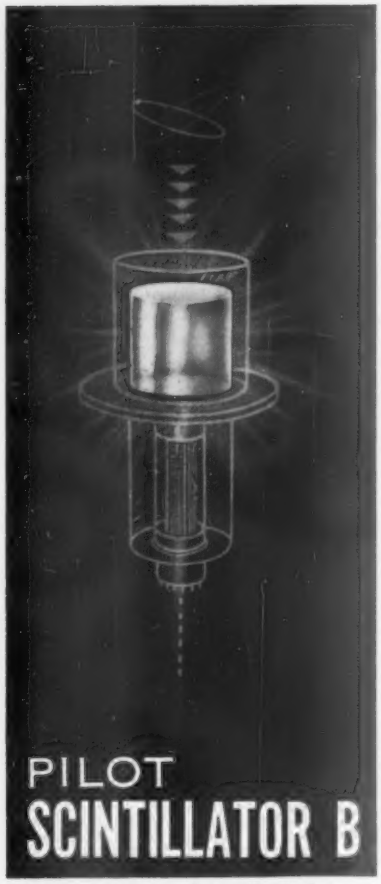


FIG. 3. IMPROVEMENT results as one changes round cylinder into truncated cone. 624-kev electrons produce greater pulses and better resolution in cone



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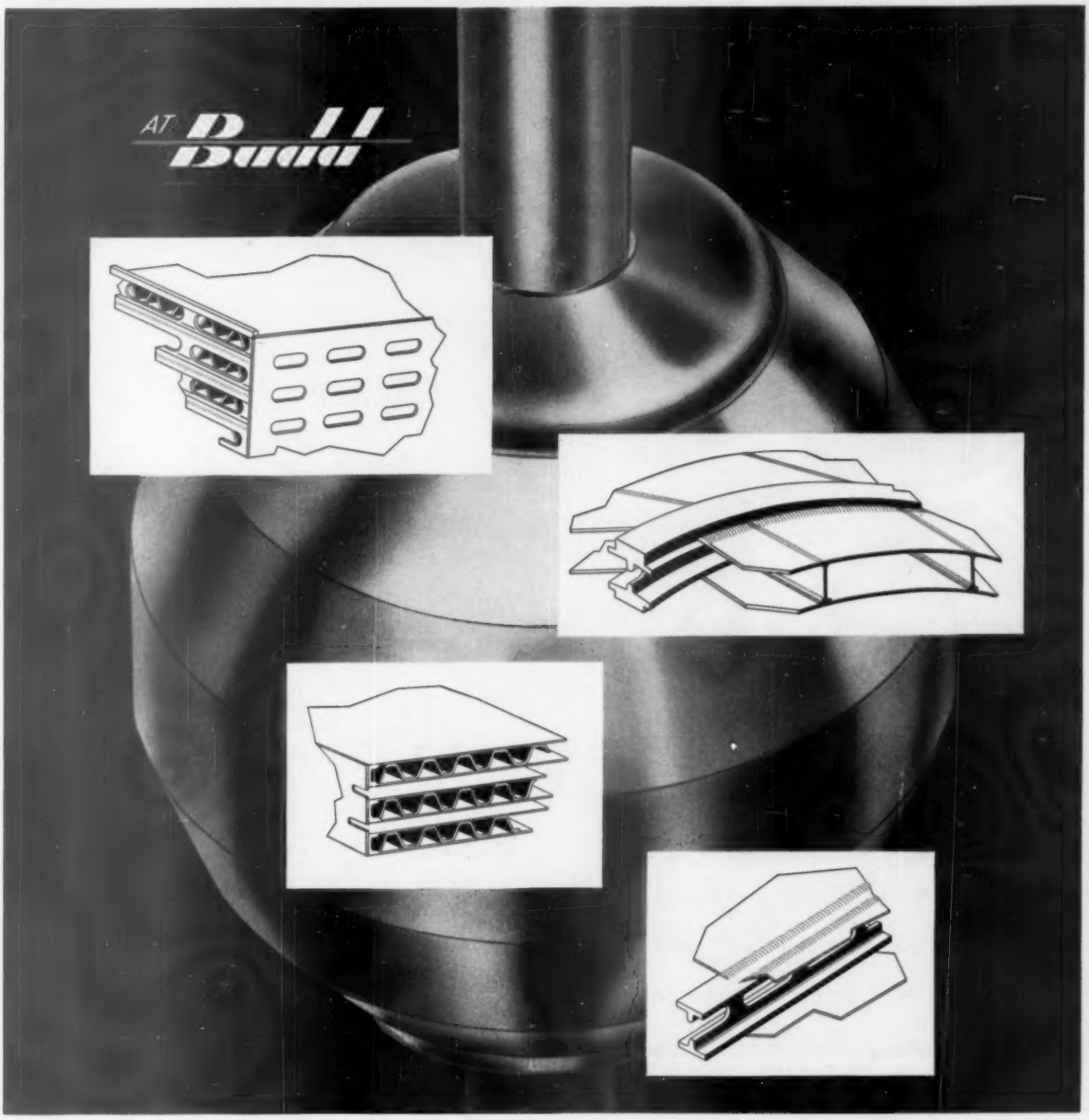

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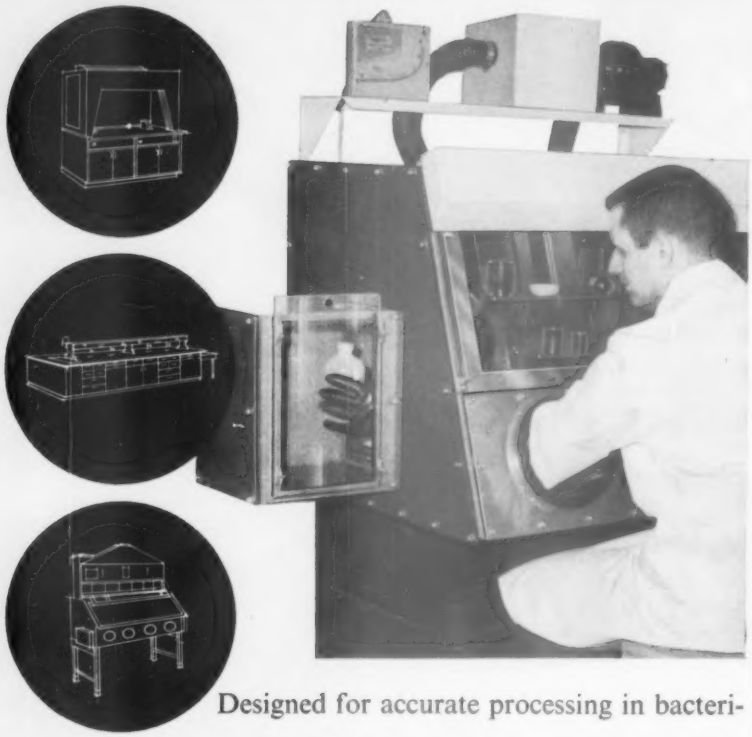

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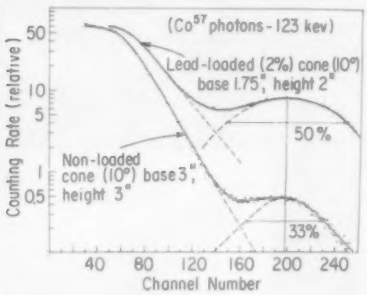

FIG. 4. PHOTON PEAK appears as 123-kev gammas are detected with plastic cone. Lead loading increases total-absorption fraction but worsens resolution

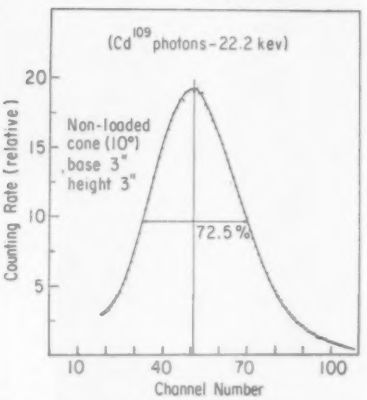

FIG. 5. WELL DEFINED PEAK appears in detection of 22.2-kev photons. Small energy makes resolution a poor 72.5%, but shape of curve shows improvement in going to lower-energy photons

total-absorption peaks than large-energy ones follows from the dependence of absorption coefficients on photon energy. Only at very small energies are Compton- and photoelectric-absorption coefficients in carbon nearly equal; at most energies photoelectric absorption is very small compared with Compton absorption. For example, for 22-kev radiation the photoelectric absorption coefficient is 0.133 cm^2/gm, and Compton coefficient is 0.22 cm^2/gm; at 123 kev the values are: photoelectric, 0.00046 cm^2/gm; Compton, 0.143 cm^2/gm. It is plain that a total-absorption peak requires contributions from Compton absorption, especially at large photon energies.

The best scintillator size for total absorption is also a function of energy. By using large scintillators we can increase the fraction of absorptions that

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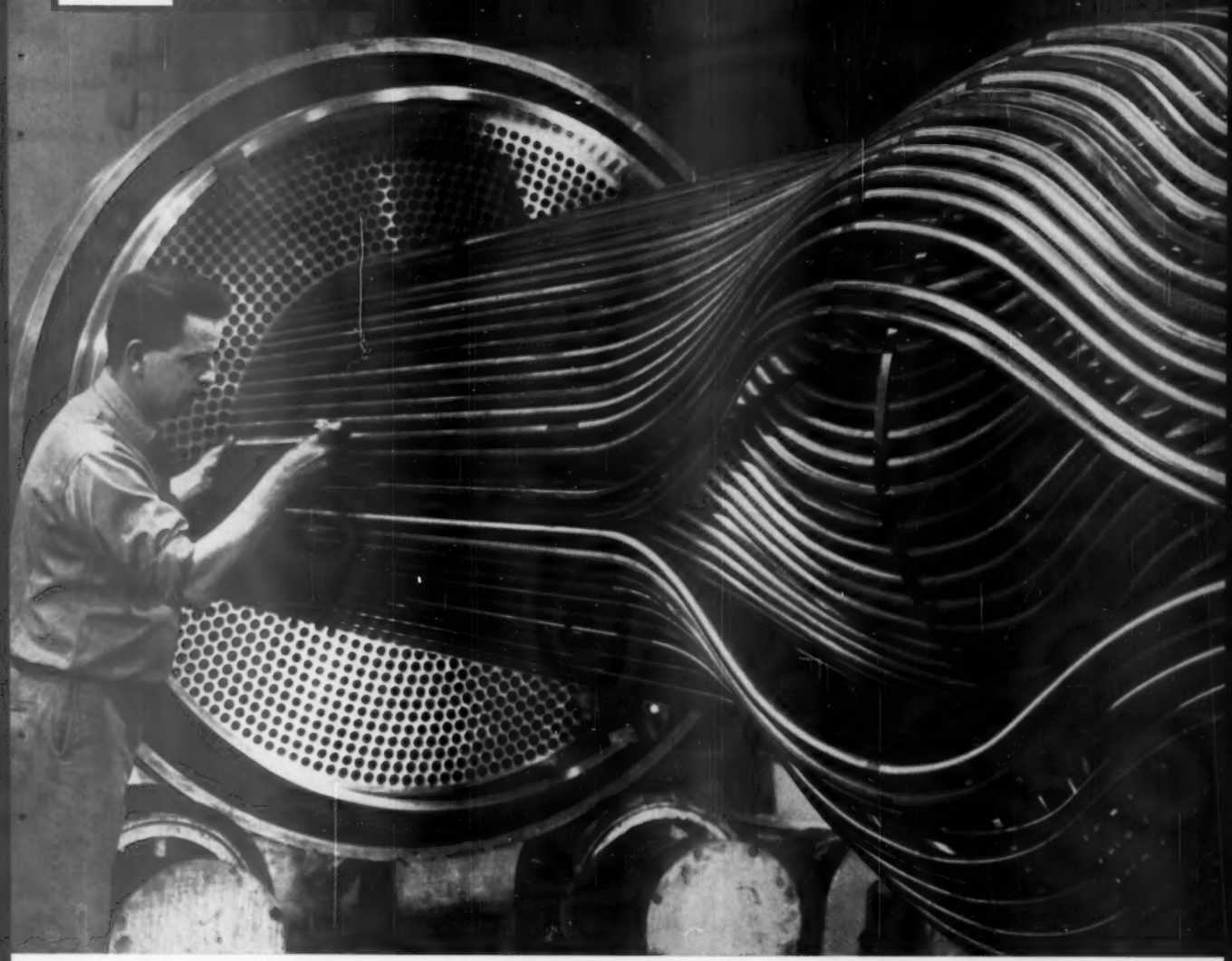

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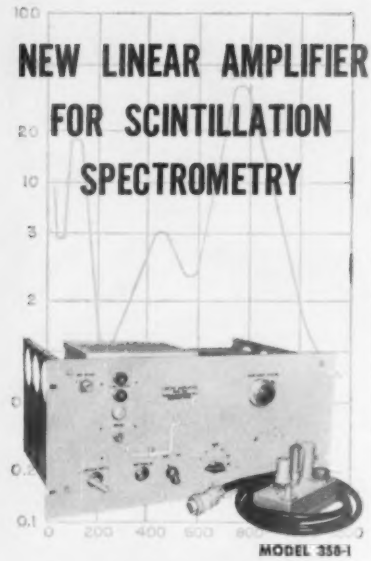

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*Developed at Oak Ridge National Laboratories by George Kelly (ORNL Type A-8).

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INSTRUMENTATION AND MEASUREMENTS

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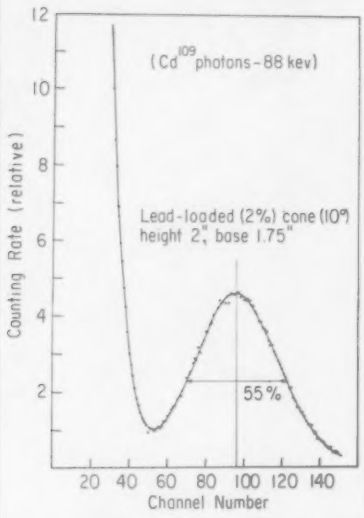

FIG. 6. LEAD LOADING leads to clear, well resolved peak with 88-kev photons from Cd^{109} source Unusually good peak comes from combining low-energy photons, lead loading and conical shape

deliver their total energy to the plastic, but then light collection is an important difficulty. The mean free path for Compton interaction of 400-kev photons is ~10 cm, and many interactions are required for total energy absorption. Therefore one can expect a major contribution from multiple Compton interactions only with scintillator dimensions greater than 10 in. With such dimensions efficient light collection is not feasible, at least not if one collects light from only one surface. For these reasons our largest scintillator is a 10-deg cone with 3-in. base and 3-in. height (lower curve, Fig. 4 and Fig. 5). All our spectra were recorded with a Du Mont 6363 photomultiplier and a 256-channel analyzer.

You will see the effect of photon energy by comparing Fig. 4 (123-kev Co^{57} gammas) and Fig. 5 (22.2-kev Cd^{109} gammas). It is plain that the 22.2-kev photons show total absorption, but their very small energy makes the resolution no better than 72.5%.

Lead loading. Another method for increasing total photon absorption is incorporating small amounts of large-atomic-number elements in the plastic scintillator. By adding 2 wt % of lead to the plastic, Pilot Chemicals has made a scintillator that combines increased absorption and rather good scintillation; its pulse heights are

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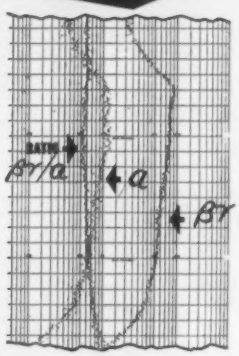

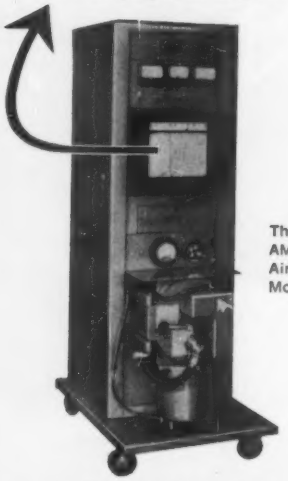

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~70% of those in their standard plastic scintillator.

In this lead-loaded plastic, the photoelectric absorption of 123-kev gamma photons is increased by a factor of ~16 with Compton absorption unchanged (Fig. 4). Reduced light output makes resolution worse than in the nonloaded scintillator. There is a better total-absorption peak with the smaller energy of the 88-kev line of Cd^{109} (Fig. 6).

* * *

We obtained all of our plastic scintillators from Pilot Chemicals, Inc., Watertown, Mass. For electron measurements they were always covered with a reflecting foil of either aluminum or Mylar.

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Nuclear Fission Produces Tritium

By E. L. ALBENESIUS and R. S. ONDREJCIN
Savannah River Lab., E. I. du Pont de Nemours & Co., Aiken, South Carolina

The triton has been definitely shown to be a product of nuclear fission in experiments we conducted (*1*). This is the first time the triton has been observed in fission, although ejection of an alpha particle for approximately each 300 fissions has been well established (*2, 3*). Analysis of samples of irradiated natural and enriched uranium and an irradiated mixture of transuranic nuclides showed a consistent ratio of fissions to tritium atoms. For the three types of materials examined, a ratio of $1\text{–}2 \times 10^4$ fissions per tritium atom was observed.

A possible application is to use tritium content as an index of fuel burnup. However, the somewhat erratic distribution of tritium between gas phase and solution upon acid dissolution of irradiated uranium is a complication. Vacuum extraction of the gas from irradiated fuel is being explored to permit recovery of the tritium in a single phase.

Experiments and Observations

Eight samples of natural uranium, irradiated over an exposure of 300–1,600 Mwd/ton, gave a fission-to-tritium ratio of $1.05 \pm 0.09 \times 10^4$. The samples on which these results were based were derived from experimental rods of uranium irradiated in a heavy-water-moderated and -cooled Savannah River production reactor. Exposure of the experimental assembly was calculated from measurement of coolant flow, temperature and flux.

Samples were sectioned from each rod, dissolved and analyzed for tritium content. Sections weighing 40–80 gm were cut from each rod, and any adherent film of tritiated deuterium oxide removed with a solution of sodium hydroxide. The uranium of each section was then dissolved in nitric acid in an apparatus designed to collect the off-gas quantitatively. The collected gas was scrubbed to remove nitrogen oxides and then was passed through a copper oxide combustion tube to convert any hydrogen to water. Tritium was measured by liquid scintillation counting. Dissolver solutions were analyzed as previously described (*1*).

About 25% of the total tritium was found in the gas phase. Approximately the same distribution of tritium was observed in the off-gas from a large-scale dissolution.

Experiments with irradiated natural uranium are under way to measure more accurately the total fission yield of tritium, including determinations of the fraction of tritium that appears in the gas phase when the uranium is dissolved in nitric acid. Preliminary results from these experiments indicate a consistent yield in spite of different exposure histories. Experiments are now in progress to establish the fission yield of the triton for other fissionable nuclides over a wide range of exposure.

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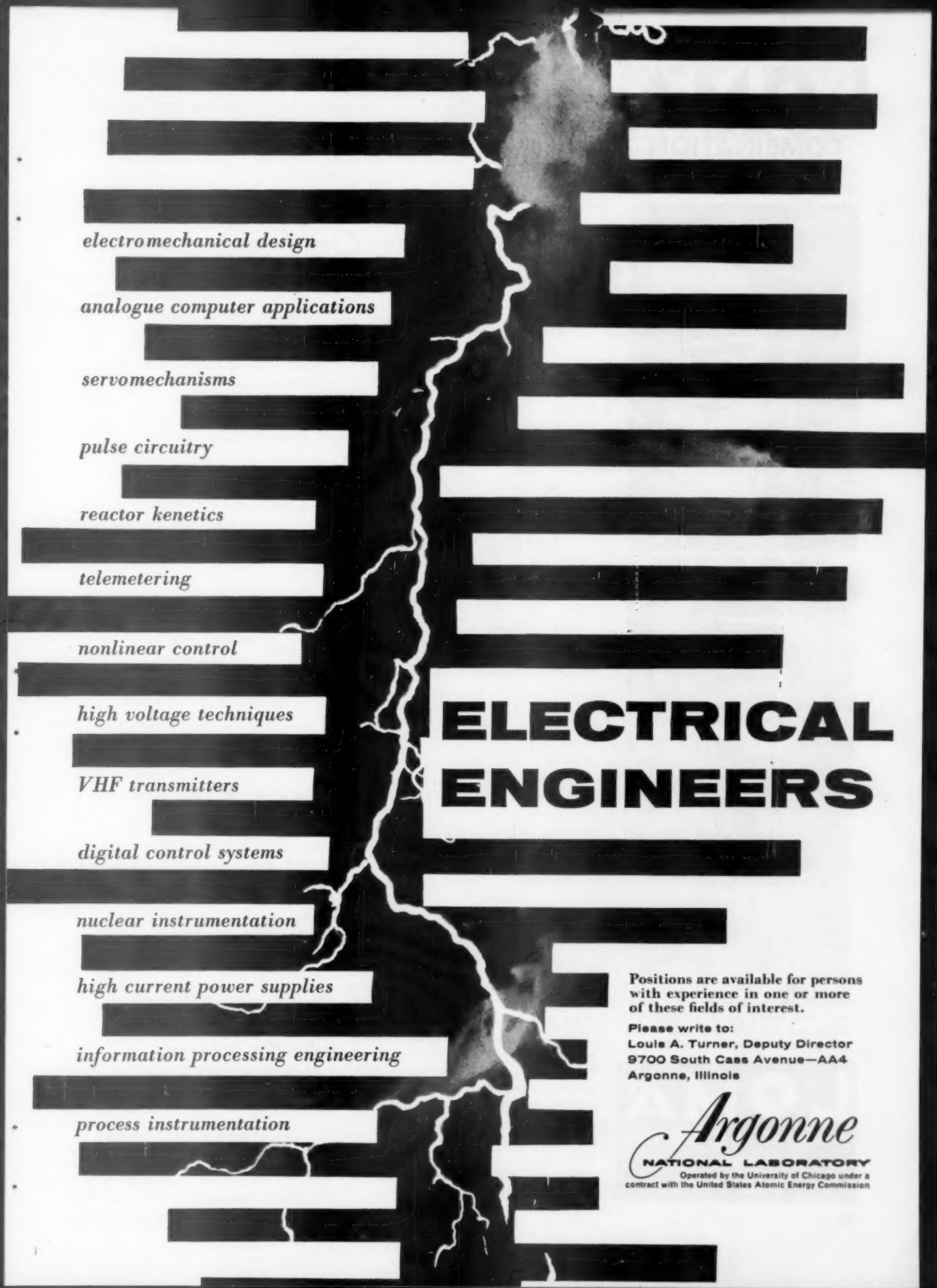
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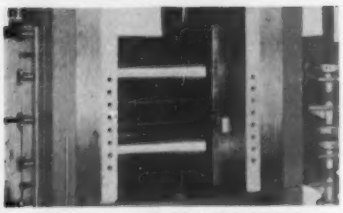
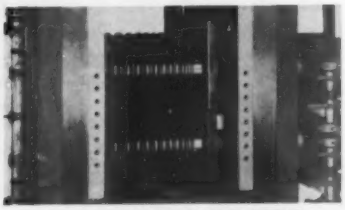


2-HIGH SHEET ROLLING SETUP



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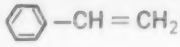
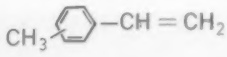
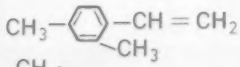
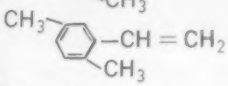
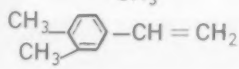
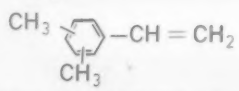
Relative Pulse Heights of Plastic Scintillators

Plastic	Formula	Relative pulse height
Anthracene		100
Styrene		39
Methyl styrene		45
2,4-dimethyl styrene		62
2,5-dimethyl styrene		55
3,4-dimethyl styrene		59
Dimethyl styrene*		60

*A mixture containing 51% of 2,4-dimethyl styrene, 17% of 3,4-dimethyl styrene and 32% of 2,5-dimethyl styrene.

Dimethyl Styrene Yields More Efficient Scintillators

By STANLEY R. SANDLER, SAMUEL LOSHAEK, EDWARD BRODERICK and PHILIP BERNSTEIN

Central Research Laboratory, The Borden Chemical Co., Philadelphia, Pa.

We have found that plastic scintillators made with dimethyl styrenes give pulse heights up to 60% higher than those made with unsubstituted polystyrene. In preparing our plastic scintillators we used 3% *p*-terphenyl as the primary solute and 0.05% POPOP as the waveshifter. Other solutes and waveshifters might prove more efficient, but this was not investigated since the primary objective was the effect of the solvent. (Many others (*1,2*) have studied the effect of solute composition on the pulse height but relatively little is known about the effect of the plastic solvent.)

The table shows the relative pulse heights obtained with 2.3-Mev Pa^{234} beta rays in a test on various dimethyl-ring-substituted plastics and on styrene and methyl styrene (vinyl toluene), which have been widely studied. Similar results were obtained with 0.6-Mev Cs^{137} gamma rays. All pulse heights are relative to an anthracene crystal of the same dimensions.

2,4-dimethyl styrene gives the most efficient plastic scintillator with a pulse height almost 60% higher than that from polystyrene. Scintillators based on copolymers of dimethyl styrenes with styrene or vinyl toluene give pulse heights that decrease linearly with styrene or vinyl toluene content. Not one of a large number of other plastics studied (but not tabulated here) is more efficient than the 2,4-dimethyl styrene.

Dimethyl styrene and plastic scintillators made from them are available in experimental quantities from the Dajac Laboratories of our company.

Fabrication and Testing

Methods for the preparation of dimethyl styrene monomer have been described (*3, 4*). Plastic scintillators were made by the following procedure (*2*): 10 gm of monomer and the required amounts of *p*-terphenyl (3%) and POPOP (0.05%) were placed in a 20-mm-i.d. pyrex vial. The mixture

was outgassed by alternate freezing and cooling and sealed under vacuum. Polymerization was carried out in a 110° C oil bath for 3 days followed by heating for one day at 170° C. After cooling, the scintillator was removed and machined to a thickness of 11 mm and polished on one face.

Pulse heights were measured as follows: The photomultiplier was an RCA 6199. The average pulse height was taken as the bias voltage setting required for a particular counting rate (corresponding to about ½ of the incoming radiation). Pulse heights so determined agreed within experimental error with those determined from the area under the counting-rate vs. pulse-height curve. Pulse heights were reproducible to ±2 units. All values are reported relative to an anthracene crystal of the same size whose value is arbitrarily taken as 100.

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1. L. J. Basile *J. Chem. Phys.* **27**, 801 (1957)
2. R. K. Swank, W. L. Buck *Phys. Rev.* **91**, 92 (1953)
3. D. T. Mowry, M. Renoll, W. F. Huber *J. Am. Chem. Soc.* **68**, 1105 (1946)
4. C. S. Marvel, J. H. Saunders, C. G. Overberger *J. Am. Chem. Soc.* **68**, 1085 (1946)

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Fuel Damage in WTR Incident

In the course of a calibration run on April 3, one of the uranium-aluminum tubular fuel elements in the Westinghouse Testing Reactor failed and spread fission products through the reactor cooling system (for a description of WTR, see NU, Nov. '56, p. 138; news of the fuel failure is given in NU, May '60, p. 26, July p. 28). No radioactivity spread outside the reactor site. When decontamination of the reactor permitted, most of the fuel elements were lifted out of the core.

As shown in Fig. 1 each fuel element consists of three concentric fuel tubes, which surround a central unfueled mandrel tube in which specimens can be irradiated. A three-finned end fitting (not shown) on either end holds each assembly together.

After all fuel elements except the ruptured one (which had just been loaded in the reactor before this calibration) had been removed, a 500-lb force was needed to pull out the upper third of the failed element, which is shown in Fig. 2. The remains of the lower two-thirds stuck tight in the core and had to be sawed out.

Disassembly revealed that the two inner tubes had melted away to within about 6 in. of their tops, while the outer tube had about 11 in. fairly intact. However, Figs. 3 and 4 show that a surprising amount of molten fuel alloy had run out from between the cladding; externally this section seemed sound. Detailed post mortem metallurgical and chemical examination of the failed element are planned.

Since heat-transfer analyses of WTR operating conditions indicate that failure could not have occurred unless the element had a bond defect greater than ½ in. in diameter, spare fuel elements were examined carefully to learn of possible defects. Many small defects and faulty dimensions, as well as blisters, were found in the mechanical inspection. When the elements were fabricated, the bond was verified only by a blister test. In this reinspection, ultrasonic tests spotted many poor bonds and cracks, foreign inclusions and voids in the fuel. Defects ranged from 0.015 in. to greater than 1 in. in diameter. Typical flaws are shown in Figs. 5 and 6.

From this evidence Westinghouse* concludes that fuel specifications were too loose and inspection was lax. To keep the increase in the hot-channel factors caused by defects below 10% in future fuel, WTR specifications will call for ultrasonic inspection to prove that no defects are larger than ⅛ in. In view of the tightened specifications, Westinghouse says "this particular batch of fuel was of questionable quality, with over 1,464 defects having been found, and with over 133 of them over ½ in. in size in a sampling of 237 tubes."

This experience with WTR certainly raises questions about the usefulness of the blister test for checking the bonding of fuel for high-power test reactors. Although they are more expensive, ultrasonic tests might find their way into more fuel specifications. Other questions might be asked about current practices in fabricating U-Al fuels. How effective is open-pot vs. vacuum melting in eliminating gas inclusions? How sound are chemical analyses of samples from the top, middle and bottom of a fuel-alloy ingot—might a radiation-count scan determine U concentration and uniformity better? Can a thick fuel plate be bent 360 deg without risk of shearing along the clad-meat interface? Unless answers to such questions are found either fuel-fabrication costs will rise or the need to decontaminate reactors will be repeated.

—THE EDITORS

* The data presented here are from "Report on WTR Fuel Element Failure April 3, 1960," Report WTR-49 (Westinghouse Electric Corp., July 7, 1960).

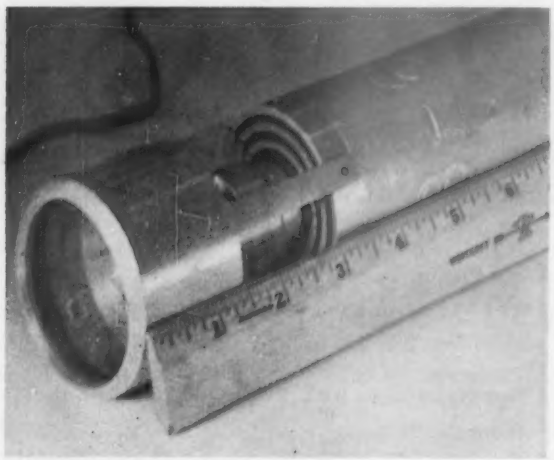


FIG. 1. Each of three fueled tubes in a WTR fuel element is made by bending a regular picture-framed Al-clad U-Al flat plate along its length, then brazing the seam. When newly inserted or fresh, each assembly contains 200 gm U^{235}

FIG. 2. Appearance of the fuel fragments is evidence of the suddenness and vigor with which the fuel element melted

FIG. 3. U-Al fuel alloy melted and ran out from between the Al cladding as high as 5½ in. from the top of the center tube (top 3 in. of tube is Al end closure) (as cut by hacksaw; unpolished)

FIG. 4. Inhomogeneity in the U-Al fuel alloy or poor bonding to the cladding is suggested by small (~⅛-in. thick) holes such as this one (as cut by hacksaw; unpolished)

FIG. 5. Typical void in the fuel alloy that was located by ultrasonic tests of spare elements

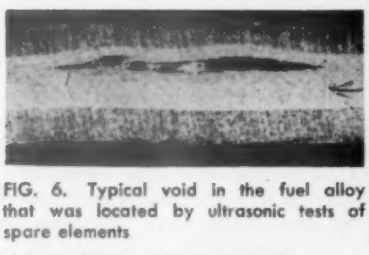
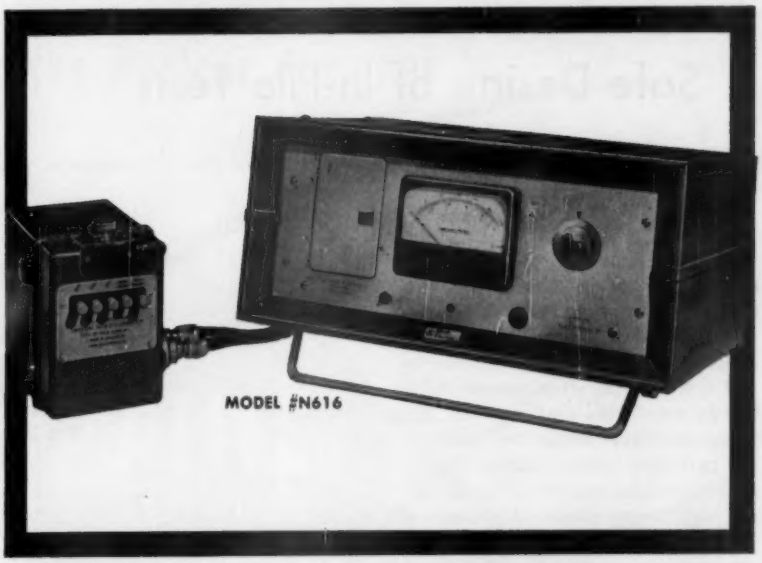


FIG. 6. Typical void in the fuel alloy that was located by ultrasonic tests of spare elements



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Safe Design of In-Pile Tests

By THEODORE BERESOVSKI, *United States Atomic Energy Commission, Brussels, Belgium*

A large in-pile experiment is nearly as complicated, in terms of hardware and instrumentation, as the test reactor in which it is to be placed (see Fig. 1). In addition, to fit into the reactor the test system must often assume weird, tightly constricted configurations; this is especially true for the test section—the part that must withstand intense neutron and gamma irradiation, usually at high temperature and pressure. There are potential hazards enough in operating a system such as this out-of-pile; clearly when the experiment is put into a reactor the potential interaction between the two systems will compound the hazards inherent in the reactor or experiment alone.

The design of an in-pile experiment must guarantee that none of these hazards will come to pass with any reasonable probability, during both normal and abnormal operation. Moreover, the design must also be safe from hazards during fabrication, testing, insertion, and withdrawal of the test apparatus.

To understand how the design engineer can successfully meet this most challenging hazards evaluation problem, we will first discuss the general classes of hazards associated with irradiation experiments and methods by which they can be analyzed and then we will deal with techniques for reducing or eliminating hazards.

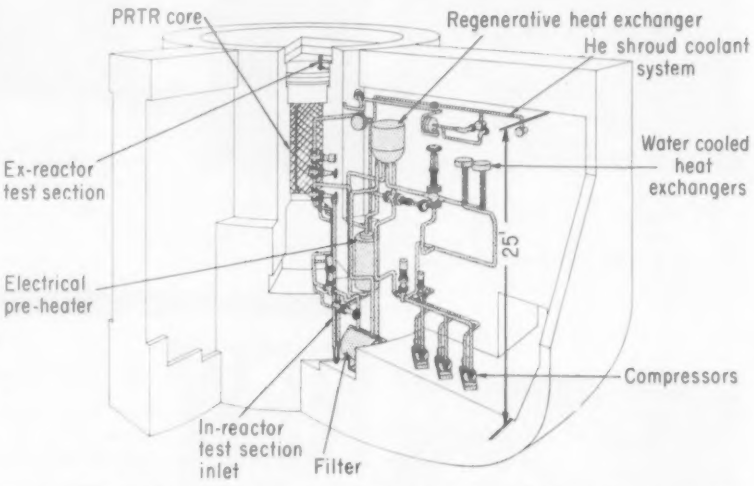

FIG. 1. PRTR IN-PILE LOOP dwarfs core of Plutonium Recycle Test Reactor. Loop coolant is CO_2; flow will be up to 15,000 lb/hr at maximum pressure and temperature of 500 psig and 1,500° F. Maximum power generation will be 500 kw. Loop equipment forms package of roughly 5 ft × 20 ft × 25 ft and supplies single in-pile test section (which replaces one of reactor process tubes) plus identical out-of-pile test section (which serves as control). Loss of either coolant flow or pressure or high outlet temperature in loop scrams reactor. Last ditch safety injects water into test section. *Courtesy of D. E. Baker et al, G.E.-HAPO*

Safety Evaluation

Each irradiation experiment must be analyzed (a) to ensure safety under normal operating conditions and (b) to ensure safety under all "credible" abnormal circumstances *involving the reactor* as well as the test apparatus.

Specifically, four major hazards must be examined, their probabilities assessed, and their potential consequences determined: excessive temperature, material and component failure, sudden reactivity change and chemical explosion. These conditions are often interdependent.

Excessive Temperature

The designer must show conclusively that the normal operating temperatures for his experiment do not exceed the limits of any of the components. Furthermore, he must show that all "credible" abnormal circumstances will not cause temperature changes great enough to jeopardize the experimental equipment or exceed temperature limits imposed by the reactor (see Fig. 2).

To arrive at these guarantees the designer first evaluates the heat-generation rate in the experiment and assures himself that the heat generation can be reduced fast enough and for a period long enough to avoid dangerous transient or steady-state conditions. He then sees that, after a reactor shutdown, the heat can be removed from the experimental equipment either until the equipment can be withdrawn or until, owing to radioactive decay, excessive temperatures are no longer possible. He may use elementary heat-transfer methods to estimate maximum temperatures in the apparatus, but is careful to offset the uncertainties introduced by these methods with adequate safety factors.

A study (*1*) by the Heat Transfer Subcommittee of the Phillips Reactor Safeguards Committee delineates the uncertainties in temperature calculations for forced-convection, nonboiling water systems. The Subcommittee recommends that the heat-transfer characteristics of all experimental equipment to be installed in the ETR and the MTR be determined from the modified Colburn equation (*1*). (All properties are evaluated at the average between the bulk water temperature and the wall temperature. The exponent of the Prandtl number is set equal to 0.300 rather than 0.333.) The Subcommittee also recommends that a safety factor of 1.2 be included in these calculations. Throughout the study, the analysis of experimental uncertainties was emphasized, and the conclusions are directly applicable to all irradiation experiments.

As a result of its study, the Subcommittee has requested for each experiment a hot-spot, hot-channel analysis in which numerical values are assigned to all uncertainties. The heat-transfer effect of each uncertainty is estimated by determining three quantities: A

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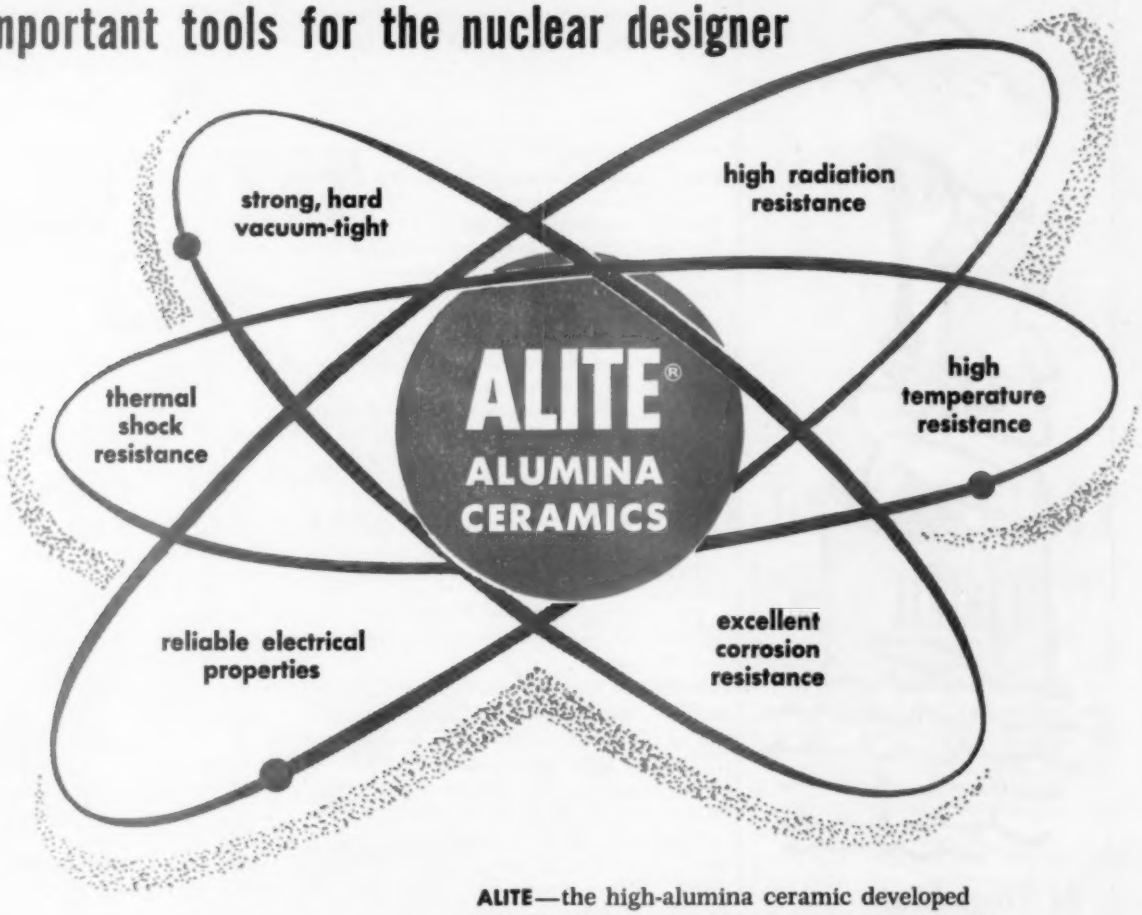

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Hot-Spot Factors for Typical In-Pile Loop

Uncertainty	*Hot-spot factors*‡ F_b	F_h
Effect of plenum-chamber conditions upon flow distribution to parallel reactor channels	1.02	1.02
Effect of fuel-element warping	1.04	1.03
Combined effect of tolerances for core alloy in fuel-element thickness and concentration	1.08	1.21
Combined effect of tolerances on clad-thickness and water-channel dimensions	1.40	1.26
Precision of flux-distribution calculations	1.20	1.20
Local variations in axial heat-flux distribution		1.10
Accuracy of fuel thermal conductivity		
Precision of heat-transfer-coefficient correlation		1.20
Variation in heat-transfer coefficient on the fuel-element surface		1.50
Precision in measurement of power output	1.10	1.10
Inaccuracies in measurement of channel temperature rise*	1.10	
Deviations from theoretical mixing†	1.30	

* Replaces hot-spot factor $F_{\Delta T}$ when temperature rise in each channel is monitored.
† Replaces water-temperature-rise factors in $F_{\Delta T}$ when coolant channels are interconnected.
‡ See text on this page for definitions.

hot-channel factor $F_b = \Delta T_{bulk}$ (max)/ΔT_{bulk} (nom), a hot-spot factor $F_h = \Delta T_{film}$ (max)/ΔT_{film} (nom) and a ratio $F_{\Delta T}$, which takes into account *all* additive temperature uncertainties that are not reflected in either F_b or F_h. The product $F_b \times F_h \times F_{\Delta T}$ multiplied by the average temperature gives an estimate of the maximum temperature to be expected. If this maximum is below the temperature limitations of the experiment, the heat-transfer analysis can be considered complete and the conditions acceptable.

If the predicted maximum temperature exceeds the maximum allowable, the analysis must be further refined to determine the probability that the maximum temperature might actually occur. Sometimes uncertainty factors are inadvertently duplicated; these duplications must now be carefully eliminated. The designer must also assess the likelihood that several factors will combine to produce the excessive temperature. Often this probability is so low that it can be ignored. In any event, the hot-spot, hot-channel analysis enters as an essential factor in the final decision as to whether or not an experiment is safe enough to be undertaken.

Component Failure

Failure of materials and components during a test can result not only from abnormal temperature but also from one or more of the following conditions: loss of strength, increased pressure stress, changes of state, corrosion and radiation damage. Unfortunately, stress phenomena outside the elastic range and the self-equilibration of thermal stresses are very difficult to analyze mathematically. In embrittlement, fatigue, shock and thermal-cycling phenomena, comparatively minor changes in composition or environment can have very pronounced effects. Under these conditions, empirical testing, although costly and time-consuming, is often the only reliable approach. But even though experimental data are carefully analyzed and compared with the results of engineering calculations, safety factors are still unavoidable. These factors can be as high as 4 or 5 for containment jackets or shells, and may approach unity for the life-time endurance of a high-temperature, high-priority, military test component that is otherwise adequately protected against failure.

To calculate the maximum stresses, the designer must first estimate the maximum pressure. Given the heat-transfer analysis, which establishes the maximum temperatures to be expected, he estimates pressure increases in solids from expansion coefficients, in liquids from vapor-pressure data, and in gases by applying the gas laws.

The designer must also not forget changes of state. Usually these are accompanied by expansion, and he must show either that no harmful

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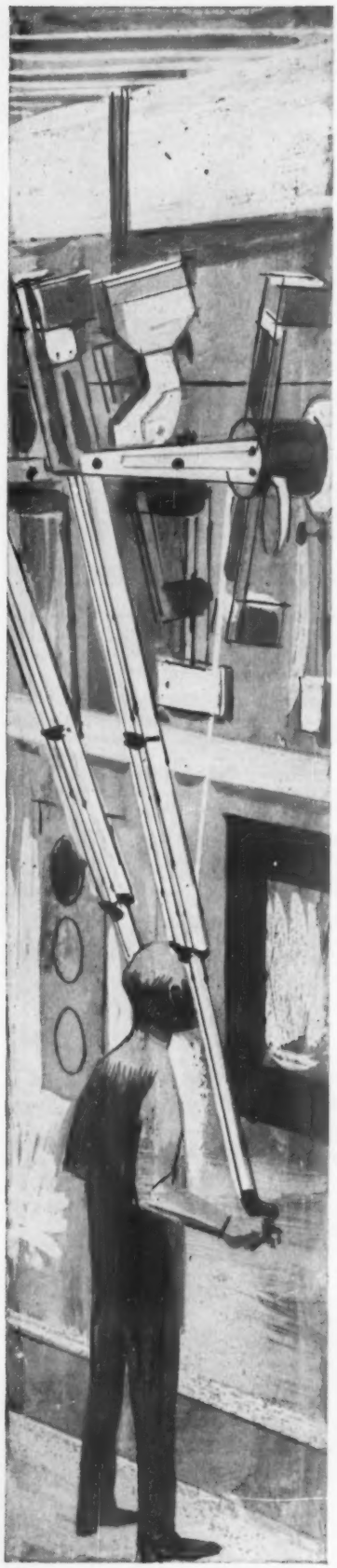

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effects can result or that the temperature control incorporated is good enough to rule out any changes of state. In water systems, for instance, the extremes of freezing and boiling must be avoided. In some liquid systems, slug formation can cause troubles. A liquid-salt solution can separate and form solids likely to damage a centrifugal pump. A solid slug in a liquid-metal system could stop circulation, causing excessive temperatures.

Corrosion, erosion, and mass transfer can also lead to dangerous conditions through the formation of plugs at cold spots in circulating systems. These effects depend on fluid velocity, impurity content and temperature. The purity-control system deserves special attention because harmful impurities, such as oxygen, must be kept within safe limits. Corrosion and erosion can penetrate materials deeply and reduce thicknesses significantly. After evaluating these effects, the experimenter must design the equipment to allow for the loss of strength that will result from corrosion and erosion.

Irradiation damage, by changing the physical properties of materials, can affect the safety of an experiment. Although we have considerable understanding through solid-state physics studies, the existing theory does not predict irradiation effects very precisely and one must rely on what empirical information is available. When conclusive data are not available, safety may require a series of preliminary irradiations in which integrated flux values are successively increased but each time are kept within the limits to which the data from the previous test can be reliably extrapolated.

Reactivity Changes

Possible reactivity changes must be foreseen and closely controlled to avoid damage to the experimental equipment as well as to the reactor itself. Experiments involving significant amounts of fissionable material, or material with large neutron-absorption cross sections or moderating ratios, are particularly dangerous. Such experiments cannot be performed unless the designer can prove that sudden changes will not dangerously increase reactivity. In conducting experiments of this kind, some of the possibilities that one must guard against are changes in position of the reflector, moderator, or fuel materials caused by inaccurate place-

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ment, meltdown, explosion, or radiation-induced disintegration.

Liquid- or dispersed-fuel tests present unique problems. In-pile circulating loops, ordinarily used to develop these types of nuclear fuels, have large amounts of fissionable material in the out-of-reactor sections of their primary circuits. Rapid precipitation and concentration of fissionable material in the in-pile sections could cause a power excursion. To analyze this possibility, the designer must evaluate the composition and properties of the fuel, particularly its deposition characteristics at various velocities and temperatures under the normal and abnormal operating conditions of the proposed experimental apparatus.

In many experiments performed in high-power-density test reactors (such as the MTR and the ETR), the reactivity effects of experiments are important to the operator not only for the reasons already noted but also because they affect the reactor fuel loading. Since these reactors may contain dozens of experimental assemblies, with both negative and positive reactivity effects, it is very difficult to calculate their total effect accurately. Hence the construction of a critical assembly solely for reactivity measurement may be justified, as it was at the MTR and ETR.

Chemical Explosions

The possibility of a chemical explosion is determined principally by the compatibility of the reactants, the extent to which they are intermixed, their relative amounts, and their temperatures. If these are known and if the results of previous experiments are applied, the designer can usually predict the likelihood of an explosion.

In some experiments, such as those in which water is decomposed by irradiation into hydrogen and oxygen, potentially explosive reactants cannot be completely separated. If so, the designer must make sure that the reactants cannot be present in explosive concentrations. If the possibility of explosion cannot be completely eliminated, the effects of an explosion on the container that confines the reactants must be evaluated. Under proper conditions explosions can be allowed to take place within reactors: experiments have been performed in which aluminum-uranium samples mounted on ceramic cups were exposed

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This article starts on page 106

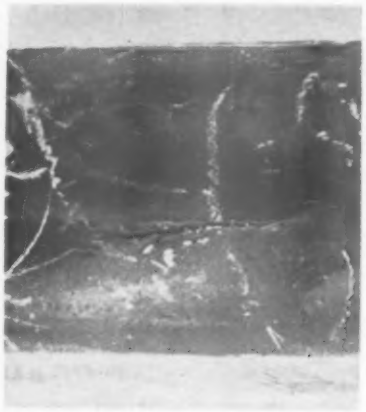

FIG. 2. RUPTURE (inside view) of high pressure water loop operating in ETR. 348 SS tube wall failed after localized overheating over 1,400° F. Design conditions were 2,000 psi and 600° F. *Courtesy D. R. DeBoisblanc, Phillips Petroleum*

to water and exploded inside the MTR.

If the designer cannot decide whether an explosion hazard exists on the basis of analyses alone, he may be able to carry out an experimental program to further evaluate the risk. Otherwise, he is forced to assume that an explosion may occur and to design the equipment accordingly.

Safe Design

Unfortunately total elimination of all hazards is difficult, if not impossible, and some risk has to be accepted if new experiments are to be performed. Often the risk is small enough to be disregarded in practice. At other times, the acceptability of an experiment becomes largely a matter of judging the probability that hazardous conditions will arise or that all safety provisions will fail, as well as the severity of the resultant accident.

One of the designer's main objectives is to reduce the probability of a serious accident to a negligible value. To do this he applies two basic and complementary principles of safe design: (a) he eliminates hazardous conditions in the experimental equipment as far as is possible without compromising the desired experimental conditions, and (b) he uses multiple safety provisions that operate simultaneously to ensure against major accidents.

Eliminating hazards. Hazards evaluation should be much more than an after-the-fact attempt to satisfy the requirements of a safety committee.

The designer will find it easier and more effective to eliminate hazards while the equipment is being designed rather than after it is built. Following are some of the ways potential hazards can be reduced or eliminated:

It is always advisable to test on the smallest scale that will give the desired results. Experimenters are often tempted to use large samples and full-scale test components when they are easily available, even though the required data can be obtained with smaller specimens. In experiments with small specimens one can more easily maintain very large safety factors and keep the danger of unpredictable incidents to a minimum.

If possible, all pressure-vessel designs in irradiation-test equipment should follow the conservative ASME Pressure Vessel Code, Section VIII (Unfired Pressure Vessels). Pressure and thermal stresses should be combined and the possibility of an explosion fully evaluated. Stress concentrations such as those that occur where tube diameters change abruptly should be avoided. The designer may find it advisable to incorporate expansion voids and to prestress parts to minimize stresses developed at high temperatures. Finally, specifications for in-pile tests should call for extensive reduction valving on all supply tanks; the tanks should never operate at large excess pressures.

Special design precautions are needed to prevent liquids and gases from leaking from the test apparatus. Containers for comparatively simple experiments can be designed so that they can be filled and sealed during preparation; but for more complicated experiments (particularly when gases are involved) it is often preferable to fill the system after inserting it into the reactor and to drain or purge it before removal. Test apparatus can be vented directly to the reactor off-gas system or through holdup tanks and traps. Charcoal traps are very effective if they are adequately cooled and large enough to hold up the fission products for the required time.

Welding is probably the most important way to avoid leakage and should be used wherever possible in irradiation experiments. Often the welds are difficult and some must be done in an inert atmosphere. The designer must avoid specifying welds that cannot be satisfactorily inspected as well as those that present unnecessary difficulties for the welder. (*Cont. on p. 116*)

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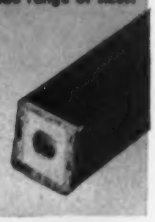

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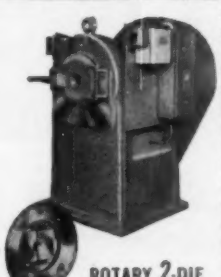

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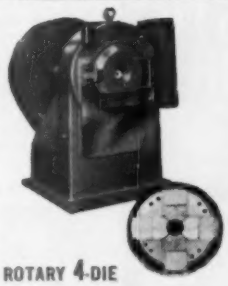

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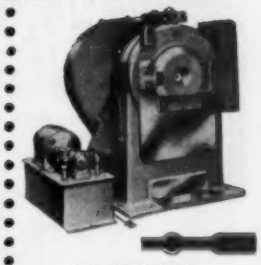

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NUCLEAR ENGINEERING

This article starts on page 106

In forced-convection experiments, pumps and blowers deserve special attention since they can easily become sources of fluid contamination or paths of escape for radioactive vapors, gases, or fluids. Canned-rotor pumps have been developed as one solution to this problem. Gas-seal pumps are another one.

Because temperature control and safety are closely related, heaters and coolers for irradiation tests must be designed with great care and should be as dependable as possible. Experiments should be designed so that any coolant failures that cannot be completely ruled out will have only mild effects if they do occur. Ordinarily, test equipment that uses the reactor coolant as the ultimate heat sink is safer in this respect than other kinds because of the large volume and the dependable instrumentation of the reactor cooling system. However, one should remember that boiling in the reactor coolant can create serious reactor control problems and thus cannot be tolerated.

Simultaneous safeguards. The probability that several independent safety devices will fail simultaneously is smaller than the probability that any of them will fail singly. For this reason, the equipment for every irradiation experiment should incorporate several safety devices in parallel, so that a major accident can result only in the event of two or more simultaneous failures.

After the experimental apparatus is inserted into the reactor, the only indication of imminent danger may be that from the instrumentation. It may not be enough, therefore, to measure only the desired test variables; it may also be necessary to measure all the variables that could indicate potentially hazardous conditions without regard for the interrelationship of the variables measured. Those frequently measured independently include temperature, pressure, flow rate, power and radioactivity.

Important variables should be measured at more than one point with fail-safe instruments. One or two of the sensing devices should be at or very near the point where the most critical conditions are expected. For example, several thermocouples should be installed at the outlet and inlet of the hottest and coldest sections of the test equipment. There should also be

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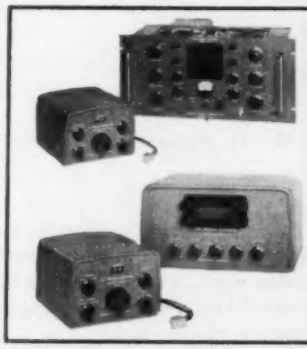

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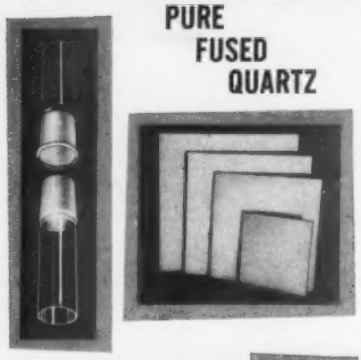

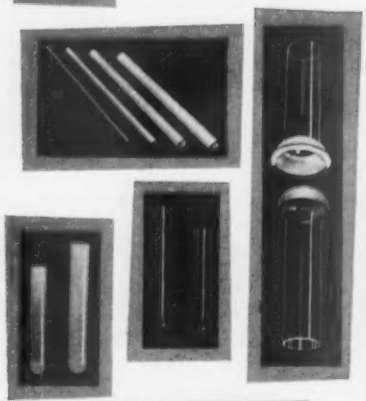

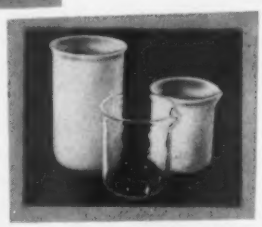

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several transmission lines leading to a number of instruments and recorders.

Instrumentation, however, can be carried too far. An over-instrumented safety system can repeatedly shut down the reactor and interrupt all experiments because of instrument failures. Loop operators are then tempted to ignore signals and warnings from instruments and to bypass interlocks that may be essential for safety.

The author wishes to thank Allis Chalmers Mfg. Co. for permission to use material prepared while he was with the company.

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WELDING 14-in.-dia Inconel pipe for the D1G prototype reactor system

Fabricating Inconel Piping Systems for TF-65 Loop and D1G Prototype

By EUGENE H. IRWIN, *Midwest Piping Company, Inc., St. Louis, Mo.*

Interest has quickened in Inconel* nickel-chromium-alloy piping for nuclear systems. Stainless steel, which has been a popular material for water-cooled reactor systems, is subject to stress-corrosion cracking when chloride ions are present in the water. But tests show Inconel is immune to this type of cracking. Inconel presents no insurmountable fabrication problems—we have built a test loop and a prototype reactor cooling system of Inconel.

Hot Test Loop

Our first assignment was to furnish and install an all-Inconel-alloy high-pressure test loop. For this loop we fabricated 125 ft of 10¾-in.-o.d. seam-welded pipe having 1-in. wall, 10-in.

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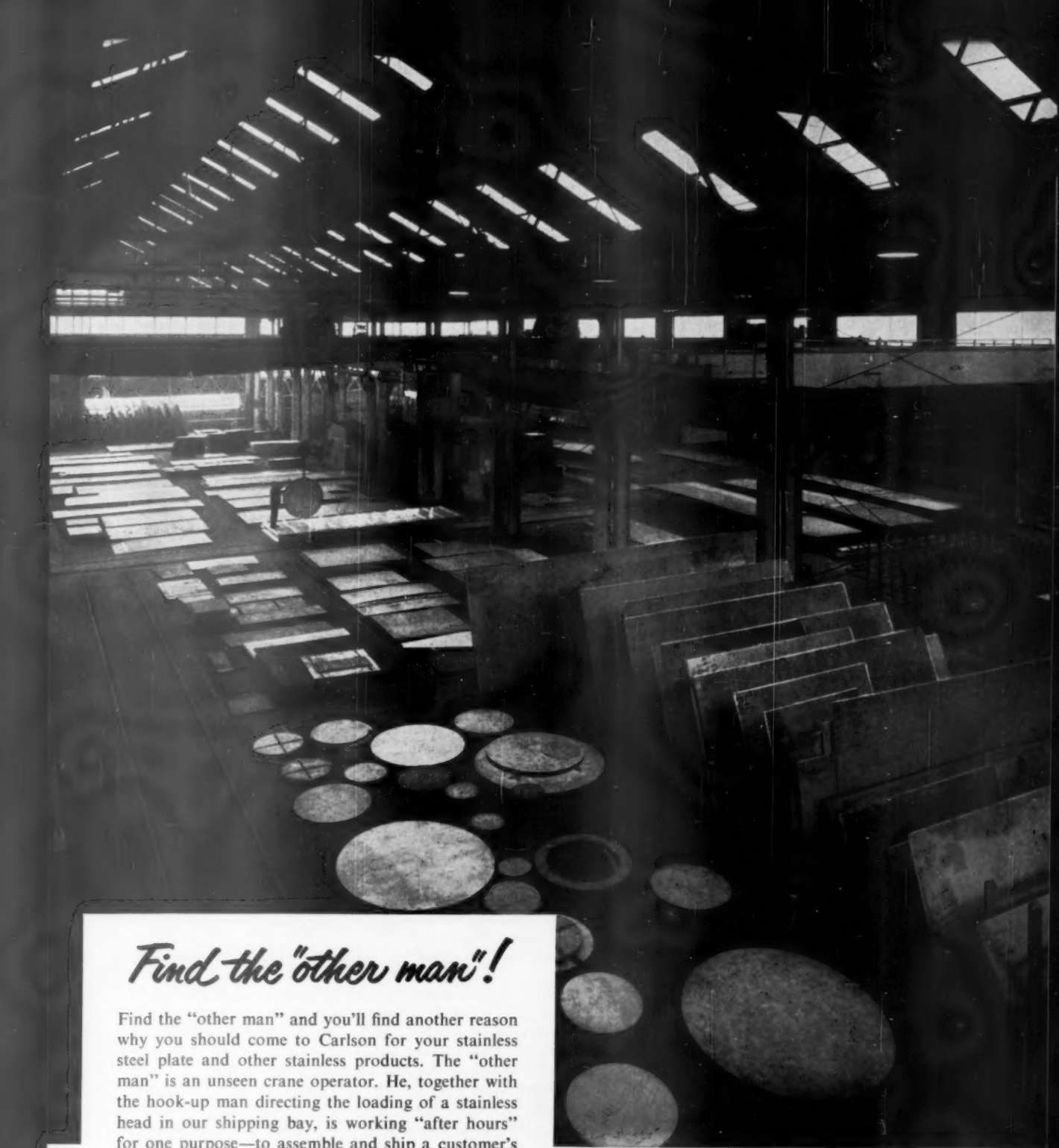

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weld ells, 3-in. weld ells, socket welding fittings and special nickel-chromium-alloy butterfly valves. So that sections of the test loop could be removed for inspection, some of the joints were of the forged lap-joint flange type. Materials, fabrication and erection of the TF-65 loop were to be in accord with the ASA Code for Pressure Piping. Although Inconel was not then covered by the Code, we demonstrated that our methods would satisfy its rules for new materials.

Inconel for D1G Prototype

Our second major assignment was to manufacture pipe and fittings for the primary cooling system for the prototype reactor for a nuclear-powered destroyer.

This project, for which pipe and fittings had to meet more stringent Navy specifications, required hot-forming 14-in.-o.d. $1\frac{1}{8}$–$2\frac{3}{4}$-in.-wall welding fittings and pipe from Inconel plate. Inconel never had been called for in such wall thicknesses and to such stringent specifications. Thus, even with the TF-65 experience to draw on, we had to develop fabrication methods and modify specifications during fabrication of the D1G piping.

Fabrication development. The D1G project presented a formidable array of questions. What welding techniques would provide the strongest and cleanest welds? How would the repeated heat-treatment cycles of the manufacturing process affect the strength, metallurgical and dimensional properties of the product? What type of welding rods would yield the most satisfactory results?

To learn the answers, we made a test specimen of Inconel pipe about 8 ft long, with a 10-in. diameter and 1-in. wall. We sectioned this piece during each stage of manufacture to learn the range of heat-treatment temperatures, metallurgical characteristics after each heat cycle, effects of welding techniques used, etc. Although the test results applied to only a limited size range, they did yield useful data on the effect of temperature on mechanical properties. For instance, repeated heatings at temperatures of 1,850–1,900° F lowered yield strength below the specified minimum of 30,000 psi. With such preliminary information to guide us, we started producing the 14-in. pipe and fittings.

Plate

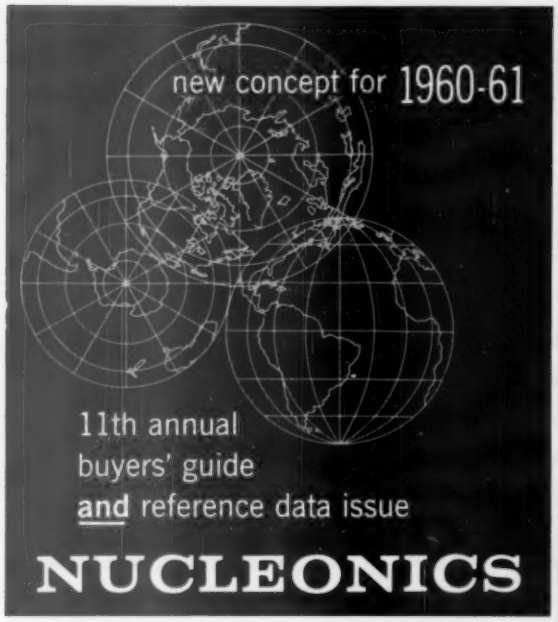
To keep down the radioactivity that would be induced in corrosion products, the purchased plate to be used in making the piping could contain no more than 0.10% cobalt. To help maintain proper mechanical properties, carbon content was in the 0.04–0.08% range. The D1G specifications required that the yield point of the 14-in. hot-formed welding fittings and pipe be 30,000 psi. This was difficult to provide since the plate from which these items would be formed also had a 30,000-psi minimum yield in the annealed state. We were concerned about the effect repeated heating might have on the yield strength (the manufacturing process involved two or three heating and forming cycles). So, to increase the range of forming temperatures, we purchased raw material hot-rolled with an as-rolled temper (35,000 psi minimum yield strength) instead of in an annealed condition. Test bars from the plate were annealed at 1,800° F for 45 min and cooled in air; then the mechanical properties were determined so as to guide our production efforts.

To find any defects in the plate, we examined the entire plate ultrasonically using both longitudinal (straight-beam) and angle-beam methods; a $\frac{1}{4}$-in. flat-bottom hole was the calibration standard for the straight beam. Also, the edges of the plate were ground and dye-penetrant examined to expose nonmetallic inclusions.

Hot Forming

The metallurgically permissible forming temperatures required in making the D1G prototype system have a definite relationship to the press tonnage used, which in turn is related to the size, length and thickness of the particular item to be formed. At lower temperatures the material is less plastic and requires stronger dies and higher tonnage. We formed the D1G elbows in halves by reinforcing the dies that we used for U-ing and sizing.

Pipe presented a more challenging problem. The long pipe resulted in a larger distribution of press tonnage, since the force could not be concentrated over a small area as it was for the elbows. We had to increase our press capacity and add a partial closing operation to our manufacturing technique. We measured the heating and



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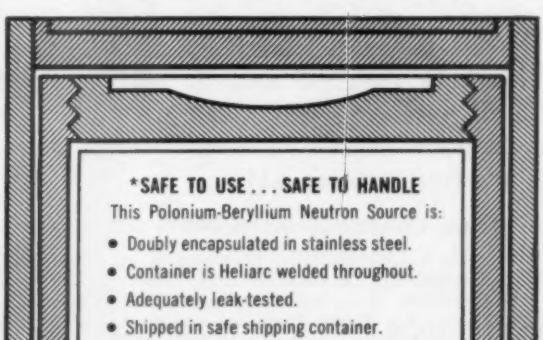
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This article starts on page 118

GROOVE IS machined in 2¾-in.-thick Inconel pipe to prepare seam for welding

forming temperatures with thermocouples and optical pyrometers. During final annealing, we made heat charts for future study.

Welding Materials, Methods

Proper selection of welding materials and techniques was essential since we had to produce a weld that was not only radiographically clear, but also physically and chemically compatible with the formed plate. Some of the welding processes normally used with steel and austenitic stainless steels are not yet suitable for high-nickel alloys. For example, submerged arc welding is fast and economical, but the available granulated fluxes contain too much silicon and heavy metals to produce consistently crack-free welds with Inconel. Coated electrodes then available were considered unsatisfactory for producing the nuclear quality welds required [however, recently a new coated electrode (BP-85 rod) has been found capable of producing welds to nuclear specifications].

Methods. The choice narrowed to consumable-metallic-electrode inert-gas (MIG) or tungsten-electrode inert-gas (TIG) methods. Welding procedures were developed for both. MIG welds were satisfactory with either semiautomatic or automatic processes, while quality TIG welds could be made either manually or automatically. Since we did not have fully automatic machines, and the work volume warranted neither equipment procurement nor further development work, we chose manual TIG

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welding for root passes and semiautomatic MIG welding for the balance. This combination readily produced commercial boiler-code quality radiographs, but the MIG process tended to give trouble with lack of fusion and oxide interference. On this basis, we decided to complete the project using the TIG process for the complete weld. Welding was slower, but less grinding and rewelding was needed—thus saving time over-all.

Filler welds. Both Inco-Weld "A" and Inconel "62" filler wires produced welds of proper quality, but "A" deposits contain enough titanium to cause precipitation hardening when the weld is heated in the 1,100–1,500° F range to which our process heats the product several times. So we standardized on the "62" wire for the TF-65 and D1G projects.

Tolerances

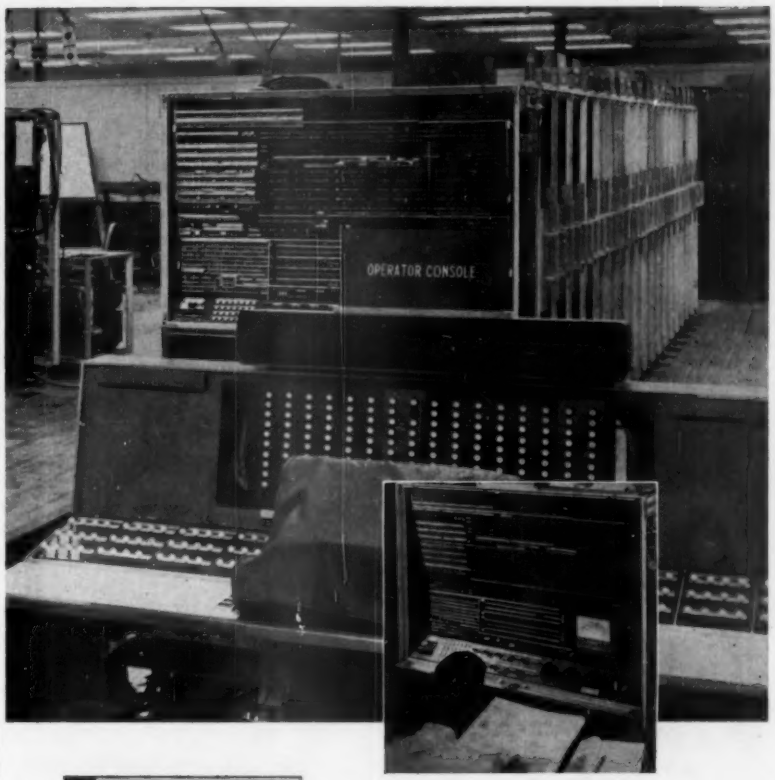
Although dimensional standards for the D1G pipe and fittings were extremely close and demanded very exacting manufacturing methods, we had no difficulty maintaining the $+\frac{1}{16}$-in. $-\frac{1}{32}$-in. outside-diameter tolerances on the elbows, since press tonnage could be concentrated during the sizing operation. But to meet the inside-diameter tolerances of +0 in. $-\frac{1}{16}$ in. on the elbows and +0 in. $-\frac{1}{32}$ in. on the pipe we internally bored the elbows and pipe on special machines. In addition to assuring a minimum cross-sectional flow area, the machining helped give the 250-microinch interior surface finish specified.

For the pipe, we found that the sizing temperature needed with Inconel prevented us from producing the close outside-diameter tolerance normally obtained. Therefore, we had to machine the outside diameter of the pipe.

Quality Assurance

Assurance of product quality was essential. So we made each fitting with extra long tangents and each section of pipe about 6 in. longer than specified so that test rings could be cut from the product itself. Some of the test rings were machined to make pieces for flattening tests, reverse bend tests, corrosion tests, tensile tests and chemical analyses of both weld metal and base metal.

In addition to the destructive tests and radiography, we performed hydrostatic, ultrasonic and dye-penetrant tests on all items prior to final cleaning for packing and shipping.



STRETCH, the world's fastest and most versatile computer, will soon be added to the array of research tools at Los Alamos Scientific Laboratory. This multi-million dollar machine, built by IBM, is 50 to 75 times faster than the IBM 704.

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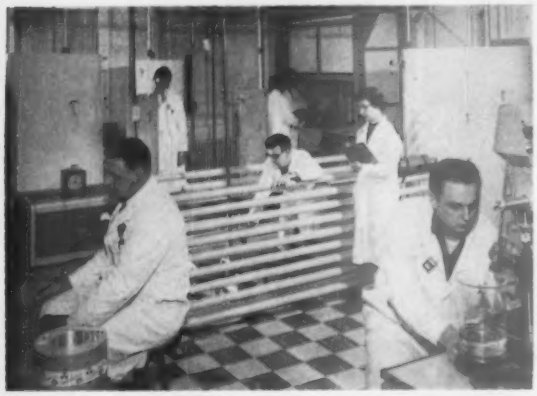
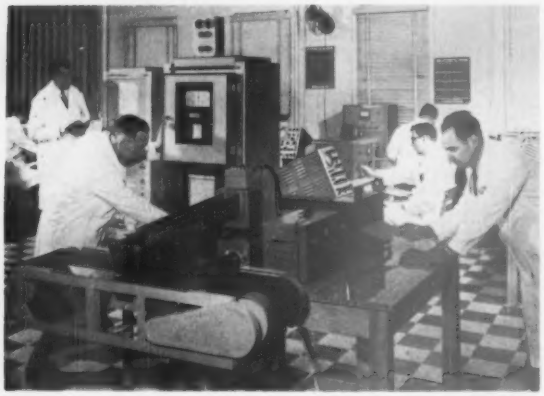


STUDENTS IN INDUSTRIAL USES OF RADIONUCLIDES make interface studies, leak tests, mixing and flow-rate measurements on process-flow system. Next session meets September 6; five in 1961. Usual student takes four- or six-week course



THICKNESS GAGING AND GAMMA SPECTROMETRY are among ~20 experiments available for students. Other subjects are Wilzbach labeling, low-level and coincidence detection, wear measurement, radiography, radiochemistry and tracing

Radionuclides in Industry— An Oak Ridge Course

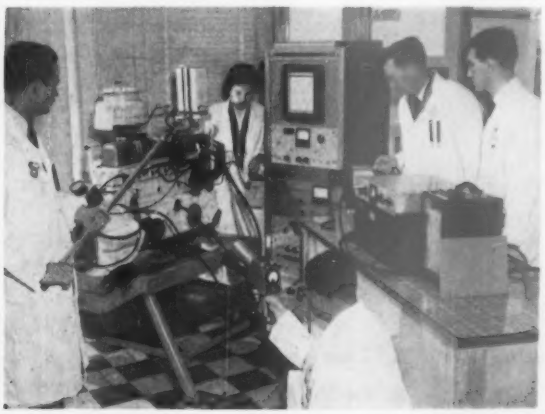
One attempt to fill the gap between actual and potential uses of radiation and radionuclides is an AEC-sponsored course conducted by the Special Training Division of the Oak Ridge Institute of Nuclear Studies. The course covers both research and routine industrial uses of radionuclides. Ralph T. Overman, Chairman of the Special Training Division, is director of the course.

The last of three six-week sessions in 1960 begins on September 6. In 1961 sessions will start on January 9, March 6, May 1, July 24 and September 11. Close coupling between course content and industrial needs has been assured by including many industrial scientists on both the committee that designed the course and the list of faculty members and guest lecturers who teach.

Requirement for the course is a bachelor's degree, preferably in a scientific field. Attendance is limited to persons who are using or are likely to use radionuclides. Preference is given to those applicants who can show advanced study and work in activities to which the use of radionuclides is particularly appropriate.

Course content is divided into four two-week parts of which a student is expected to take two or three. Part A is Basic Radiation Physics with room for 72 members. When he has completed this first part, the student chooses between Part B, Radioisotope Research Techniques for 48 participants, and Part C, Industrial Radioisotope Techniques for 24. From B and C 24 students can go on to Part D, Special Industrial and Research Techniques.

Ordinarily one is not permitted to enroll for only Part A because of the demand for the course. Those who have already had the introductory material, however, may take courses C and D.

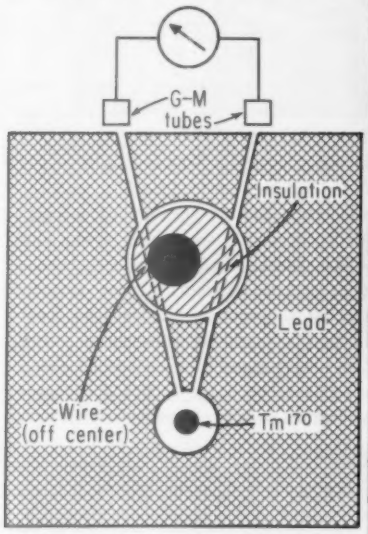


AUTOMOBILE ENGINE with radioactive piston ring enables wear tests like those performed by engine and oil companies. AEC bears costs of course except for $25 registration fee. Students live in local hotels at cost of ~$75/week

FOUR-BALL WEAR TESTER is inspected by student (left) and Vincent Guinn, advisor and often faculty member for course. Course director is Ralph Overman, Chairman of Special Training Division, Oak Ridge Institute of Nuclear Studies

Gamma Gage Finds Off-Center Wire

A differential gamma gage with balanced detectors and severe collimation is solving a problem for British manufacturers of insulated wire.* The problem is that as the insulation is applied, the wire may get off center; result: thin spots in the insulation. The solution is to split the radiation from a Tm^{170} source into two narrow channels with a small angle between



them (see sketch). Where separation of the beams is appropriate, you pass the insulated wire between them. Everything stays in balance until the wire shifts to one side in the insulation. Then one beam becomes stronger; the other becomes weaker; the detection system shows the fault. Another pair of beams with an axis at right angles to the first checks any shift of the wire in the vertical direction.

* *British Engineering and Transport*, February, 1960, p. 231

Radioactive Go-devil Hides Its Own Source

In the having-cake-and-eating-it department is a recent UKAEA development, a go-devil that is radioactive when it is stuck but not otherwise. Under normal conditions the radioactive marker source is tucked safely away in a shielding pot; you can handle the go-devil without fear of overexposure. Only when the device becomes jammed in a pipe and a pressure difference builds up around it does the source emerge and become effective.

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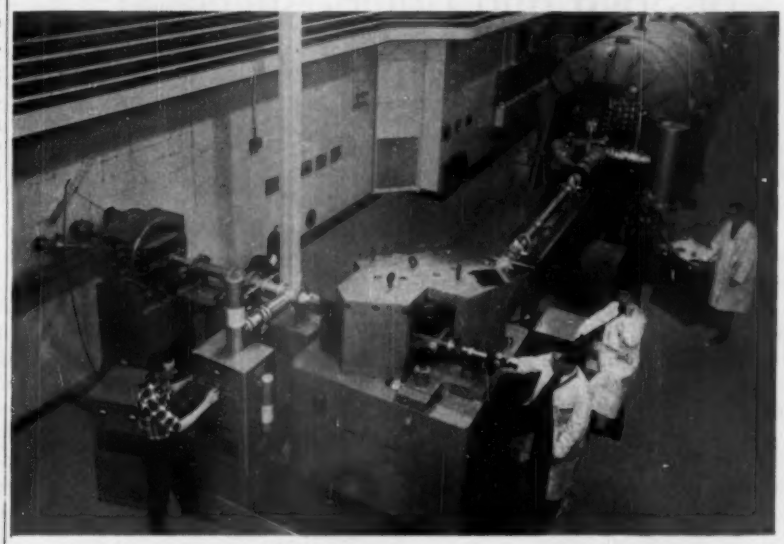

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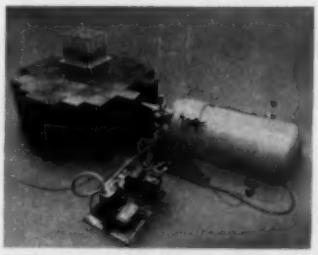

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Hydrazine from Irradiation of Solid and Liquid Ammonia

By BORIS LEVY, LAWRENCE M. EPSTEIN and GEORGE HANDLER*
Westinghouse Electric Corp., Pittsburgh, Pa.

Many experimenters have been surprised that their irradiations of ammonia (NH_3) do not produce hydrazine (N_2H_4) as expected. In contrast to these negative results, we have produced hydrazine with radiation yields of 0.1–0.2 molecule/100 ev by reducing temperatures until the ammonia becomes liquid or solid. It appears to be possible to explain the effect of temperature on yield, but further experiments are required to make sure that our explanations are valid.

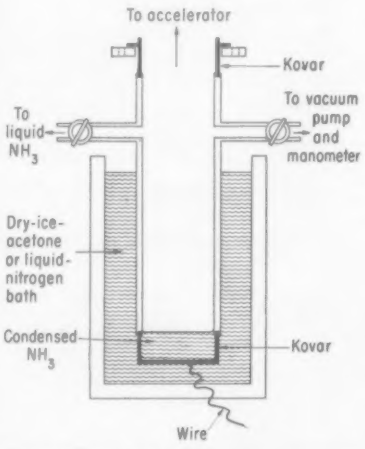
The similarity of ammonia and water systems leads scientists to expect that one of the major products of ammonia irradiation will be hydrazine in direct analogy to the production of hydrogen peroxide from water. But in the past, irradiation of neither gaseous ammonia (*1*) nor dilute aqueous ammonia (*2*) has produced hydrazine. On the other hand hydrazine has been produced from gaseous ammonia by a d-c discharge (*3*) and by photolysis in a flow system (*4*). In contrast it has been shown that hydrazine is decomposed by photolysis and other types of irradiation (*4,5*).

In our exploratory study we have used 2-Mev electrons from a Van de Graaff accelerator to irradiate ammonia at room temperature, −77° C (dry-ice–acetone bath) and −196° C (liquid-nitrogen bath). At the liquid-nitrogen temperature ammonia is solid. In our dry-ice–acetone bath ammonia is present in both liquid and solid phases. Our results are shown in the table.

Irradiations

All of our ammonia came from a single cylinder of anhydrous liquid supplied by Matheson Co. Before irradiating we analyzed it for hydrazine or other reducing substances by titration with iodine solution according to the method of Penneman and Audrieth (*6*). We found only insignificant amounts of any reducing agent (<0.0003 millimole of N_2H_4/ml of liquid NH_3).

Although they show some indication of hydrazine production, our room-temperature results are discouraging. We performed our irradiations in either sealed glass tubes or a stainless-steel water-jacketed one. With the stainless-steel tube we performed dosimetry by irradiating cyclohexane and assuming a hydrogen radiation yield of 5.3 molecules/100 ev (*7*). The dose to samples in glass tubes we determined from a previous calibration (*8*).



IRRADIATION CELL for low-temperature work holds liquid or solid ammonia in Kovar cup for exposure to 2-Mev electrons

Low-temperature experiments we did in a special cell rigidly mounted directly below a 5-mil aluminum foil that separated the cell from the main vacuum system of the Van de Graaff (see figure). With the cell in position we evacuated to $\frac{1}{10}$ mm Hg. Then we turned on the beam and adjusted it to deliver ~10 μa through a wire attached to the Kovar cup.

Without changing the established current adjustment, we turned off the accelerator and distilled ammonia into the sample section to the height of the cooled Kovar cup (~15 cm^3).

Leaving the target-current adjustment unchanged, we turned on the Van de Graaff and adjusted its energy again to 2 Mev. Measuring the current striking the sample and flowing from the Kovar cup, we sometimes found it no longer equal to the 10 μa at which it was set (see table). We are uncertain which reading is more accurate.

Dosimetry

For an independent dose measurement we inserted a piece of 0.001-in. Du Pont MSC-300 light blue cellophane at the bottom of the Kovar cup and compared its reading with dose determined from the current measurement. We measured postirradiation increase of light transmission at 655 mμ and estimated dose according to the method of Henley and Richman (*9*). Assuming a backscattering correction factor of 1.45 we found that 14.9 joules/sec was delivered to the sample.

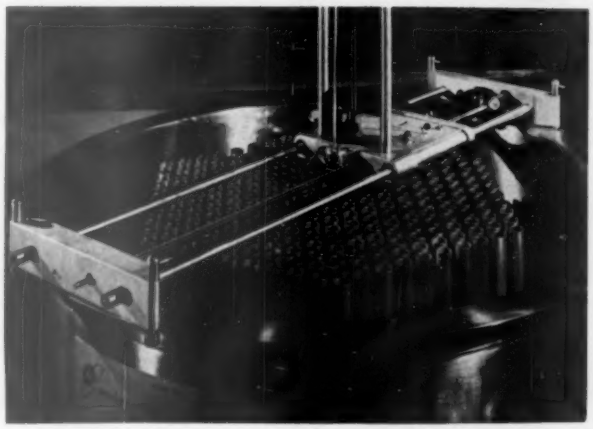
From measurement of the current from the Kovar cup we computed a deposited energy of 20 joules/sec, on the basis that all of the electrons striking the cup have energies of 2 Mev. (This is undoubtedly incorrect; secondary electrons have energies less than 2 Mev.) The radiation yields for hydrazine production in the table were calculated from currents measured during irradiation; thus they are about 25% smaller than those we would calculate on the basis of the cellophane dosimetry.

Temperature Effect

Why is there a large increase in hydrazine yield in going from room tem-

* PRESENT ADDRESS: Tufts University, Medford, Mass.

ALUMINUM GETS A NEW FACE



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Irradiation of Condensed Ammonia with 2-Mev Electrons

Run	*Temperature** (°C)	*Target current* (μa)†	*Energy delivered‡* (10^{22} *ev*)	*Iodine required for titration*		*Hydrazine yield* (10^{18} *molecules*)	$G(N_2H_4)$	*Sample cell*
				Amount (*ml*)	*Normality*			
1	room	(Sample passed under beam 201 times, receiving 1.0 megarad per pass)		0.3	0.04		~0.01	glass
2	room		9.9§	0.25	0.118	4.5	0.0036	ss
3	−77	13	16.3	15.0	0.118	270	0.17	Kovar
4	−77	10	12.5	14.8	0.11	278	0.22	Kovar
5	−77	11.2	28	¶	¶	300	≥0.11	Kovar
6	−196	10	12.5	7.1	0.118	128	0.10	Kovar
7	−196	6	7.5	6.0	0.118	108	0.14	Kovar
8‖	−196	10	12.5	3.75	0.11	62	0.042	Kovar
9	−196	5	6.25	5.6	0.11	92	0.15	Kovar

* −77° C is temperature of dry-ice–acetone bath; −196° C is liquid-nitrogen temperature. † Measured during run. ‡ All exposure times were 1,000 sec except Run 1 (see above) and Run 5, for which exposure time was 2,000 sec. § Checked by cyclohexane dosimetry.

¶ Hydrazine yield in Run 5 was measured not by iodine titration but by precipitation of 0.10 gm of benzazine with addition of benzaldehyde. Procedure was: rinse into ~60 ml water; neutralize with excess of acetic acid; to warm solution add solution benzaldehyde in 5 ml ethanol (~twice expected equivalent of benzaldehyde); on cooling benzazine precipitated as finely crystalline yellow product; filter, wash with water, dry; melting point was 93° C, unchanged by recrystallization from water-ethanol and mixing with freshly prepared benzazine. Filtrate gave no immediate reaction with additional benzaldehyde, but on standing yielded some additional product. This was separated; further aging of filtrate brought down ~5% more. We believe most of hydrazine was recovered and weighed as benzazine. $G(N_2H_4) = 0.11$ was calculated from weight of benzazine.

‖ During run 8 radiolytic gases were continuously removed. (We cannot explain small yield.)

perature to low temperatures? We can suggest three possible explanations: (1) that the high yield results from an intermolecular-reaction step favored by our solid-phase geometry, (2) that diffusion of hydrogen atoms from the reaction spurs is highly favored over that of other species at low temperatures and (3) that hydrazine is destroyed by a back reaction involving H-radical attack (*4*). This back reaction would be fairly temperature-dependent; on the other hand, the initial forward reaction may be ionic in nature and much less temperature-dependent.

One cannot choose any explanation on the basis of the data obtained so far. It would be helpful to have the yield as a function of temperature in greater detail in the region around the phase change. An abrupt increase in yield below the freezing point, for example, would suggest the first of our three explanations. We feel that there is already some indication that dry-ice–acetone temperatures are more favorable to hydrazine yield than liquid-nitrogen temperatures.

If diffusion plays an important role, investigation of other types of irradiation that produce denser tracks of interactions with ammonia than electrons would be interesting.

* * *

The authors acknowledge encouragement and helpful suggestions offered by K. H. Sun and discussions with Richard Wolfgang.

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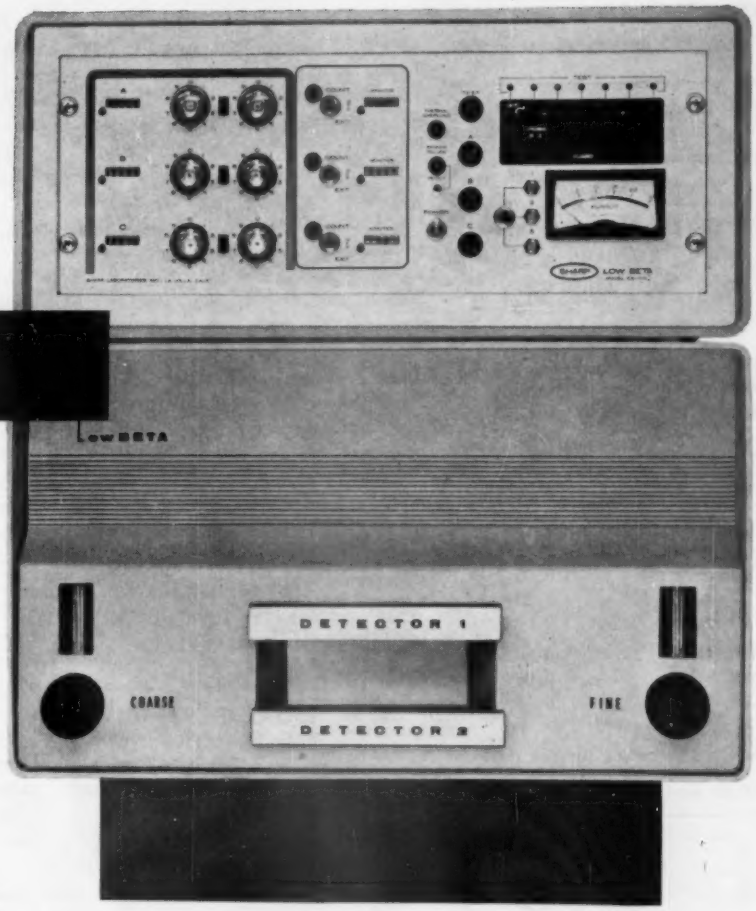

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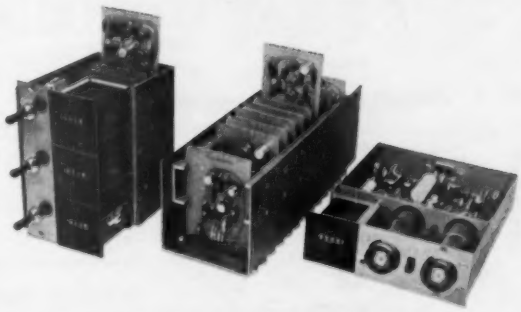

The modular construction of the Sharp low background system is shown here. Shown left to right are the timing module, the printed circuit card file containing the amplifiers and logical circuitry, and one of the three scaler modules.

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This article starts on page 87

TABLE 8—Alloy Corrosion*

Alloying addition (a/o)	*Total weight change (mg/cm²)*
Unalloyed Nb	Disintegrated†
10.5 Zr	0.67
26.1 Zr	0.67
35.7 Zr	0.66
45.7 Zr	0.55
2.45 Mo	−7.10
5.20 Mo	−1.30
7.40 Mo	0.62
4.42 V	0.42
6.59 V	0.73
8.93 V	0.59
10.7 V	0.78
13.7 V	0.50
9.41 Ti	0.65
24.3 Ti	0.52
33.8 Ti	0.33
12 Ti–0.5 Cr	0.66
28 Ti–6.1 Cr	0.20
Zircaloy-2	0.50

* Alloys were exposed for 196 days in 680° F water (*32*).
† After 42 days on test.

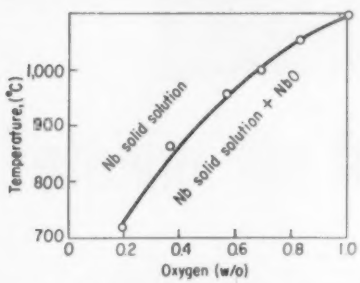

FIG. 5. OXYGEN SOLUBILITY in niobium

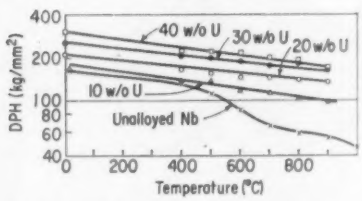

FIG. 6. HOT HARDNESS of Nb, Nb-U

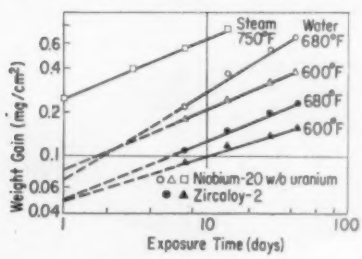

FIG. 7. CORROSION of Nb-U zircaloy

Effect of impurities on properties. As would be expected, niobium has a strong affinity for oxygen, and, unfortunately, oxygen markedly affects its properties. Figure 5 is a plot of oxygen solubility in niobium (*33*).

The behavior of the room-temperature hardness of the material indicates the effect of oxygen. Niobium containing <0.05 w/o oxygen has a hardness on the order of 90 VHN. This hardness increases almost linearly with oxygen content to ~380 VHN for material containing 0.5 w/o oxygen. Table 9 shows the effect of oxygen on room-temperature tensile properties. As temperature is increased, the effect of oxygen becomes less apparent.

Nitrogen and hydrogen are generally at a low enough level either to cause no appreciable effects or to have effects minor enough to be masked by the effects of oxygen.

Irradiation Effects

Very little information is available in the unclassified literature concerning the effects of radiation on niobium or niobium alloys. There is no reason to expect that niobium will react any differently to radiation than does any other body-centered-cubic material.

The yield strength and ultimate tensile strength should increase with an accompanying reduction in ductility. This should not be a problem, however, since the high operating temperatures will tend to anneal out the damage.

Nb-U Fuel Alloy (*35*)

As in the case of other niobium-alloy additives, uranium also increases the strength of niobium. Since niobium and uranium form a series of solid-solution alloys below 45 w/o U, samples containing 10, 20, 30, 40, 50 and 60 w/o U were screened.

Hot-hardness values obtained on slabs cast from arc-melted buttons are shown in Fig. 6. Rolling and forging tests at 2,000°–2,600° F indicated that the 30 and 40 w/o alloys are difficult to fabricate, whereas the 20 w/o alloy is easily forged and rolled. Therefore, several large ingots of 20 w/o alloy were prepared by consumable-electrode arc-melting for property determinations.

The ingots, canned in molybdenum to prevent contamination during fabrication, were upset-forged at 2,500° F with 60% reduction to slabs. The slabs were decanned and rolled in air

TABLE 9—Effects of Oxygen on Nb Tensile Strength (*34*)

Oxygen content (w/o)	*Limits of linearity (psi)*	*Ultimate strength (psi)*	*Elongation in 1½ in. (%)*
0.03	27,720	40,370	29.3
0.161	60,060	75,020	16.9
0.208	67,980	89,540	17.7
0.279	76,120	97,460	20.7
0.315	95,920	133,980	20.5
0.375	104,280	134,200	10.4
0.410	105,820	128,920	9.8
0.565	Specimen cracked before loading		

TABLE 10—Short-Time Tensile Properties of Nb-20 w/o U

Temp. (°F)	*0.2% offset yield strength (psi)*	*Ultimate tensile strength (psi)*	*Elongation (%)*	*Reduction in area (%)*	*Modulus of elasticity (10^6 psi)*
Niobium—20 w/o uranium					
75	93,200	102,000	7	21	20.3
1,600	58,100	68,400	2	16	14.0
Unalloyed niobium					
75	30,000	38,000	30		
1,500	16,000	21,000	18		
Type 316 stainless steel					
70	38,500	85,500	60	77	
1,500	18,500	27,500	42	55	

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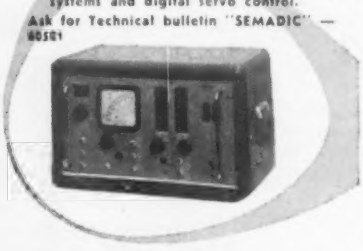

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NIOBIUM

This article starts on page 87

at 650°–800° C to 0.06-in.-thick sheet. Test pieces of the sheet were then cold-rolled (without annealing) to 0.02-in. sheet with only minor edge roughness.

Tensile-property measurements (Table 1) confirmed the strengthening effect of uranium. The 20 w/o alloy is much stronger than many commerical high-strength alloys, such as the type 316 stainless steel. Preliminary testing indicates exceptional creep strength for the Nb alloy—200-hr rupture strength at 1,600° F was 63,000 psi. Creep life should be very long at lower stress levels.

Corrosion tests were conducted in air, CO_2, NaK, water and steam. After 500 hr in air at 300° C, the 20 w/o alloy exhibited an adherent black oxide and a gain of 0.43 mg/cm². Exposures at 350° and 400° C for 100 hr caused spalling brown oxide and excessive weight gains (1.44 and 18.2 mg/cm², respectively).

In flowing CO_2 at 300° C for 50 hr, black oxide formed with a weight gain of 0.15 mg/cm². Thus, if a cladding failure occurs in a CO_2 atmosphere and the temperature is held below 300° C, no catastrophic failures would be expected for short-time exposures.

Weight gain was 0.69 mg/cm² after 1,000 hr in NaK at 1,600° F. The NaK contained 50 ppm oxygen, which undoubtedly contributed to the weigh gain.

Machined samples were exposed in water at 600° F and 680° F and in steam at 750° F for 1,000 hr with the weight gains shown in Fig. 7. The resistance of the alloy appears to be only about three times worse than that of zircaloy-2. The black oxide formed on the alloy remained adherent in water but began to spall in steam after 336 hr. In both cases, corrosion resistance is more than sufficient to allow time for fuel replacement in case of cladding failure.

Data obtained to date strongly suggests that Nb-20 w/o U alloy is the best metallic fuel yet developed for high-temperature use. At lower temperatures, the high strength should allow for exceptionally high burnup and long-life cores. The major information lacking is its irradiation stability; tests will soon be underway.

Cost of Niobium and Alloys

The current cost for Nb in sintered rod, which contains 200–300 ppm oxygen, varies from $38 to $62 per pound. Ultra-high-purity Nb (under 100 ppm oxygen) is available at higher costs. Most Nb is supplied for melting stock. However, the Fansteel 80 and 82 alloys can be purchased for about $80 per pound for heavy sheet and plate in large quantities and up to $150 per pound for foil in small quantities.

The price of Nb is following a downward trend, which should continue as the demand increases. It is not unreasonable to predict $15–20 per pound for quality melting stock in 5–10 yr.

* * *

The results reported on Nb-20 w/o U were obtained by Battelle under contract W-7405-eng-92 with the AEC Reactor Development Division.

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BOOKS RECEIVED

Propulsion Systems for Space Flight by William R. Corliss (McGraw-Hill, New York, 1960, ix + 300 pages, $10.00). A timely survey that puts into perspective the bewildering array of proposed devices for space travel that have filled the literature and the newspapers these past two years. The author defines, describes, evaluates and compares, for the technical reader, nuclear rockets, ion drives, solar sails, plasma jets and many more. At least half of the book discusses systems that have a nuclear orientation.—HLD.

The Study of Elementary Particles by the Photographic Method, by C. F. Powell, P. H. Fowler and D. H. Perkins (Pergamon Press, New York, 1959, 669 pages, $40). This volume provides a history of the development of the emulsion technique, describes the methods used and constitutes an atlas of the tracks of primary cosmic particles. It is written at a postgraduate level.

Marks' Mechanical Engineers' Handbook, 6th ed., T. Baumeister, editor-in-chief (McGraw-Hill Book Co., New York, 1959, 2,270 pages, $23.50). Among new and completely revised sections of this handbook classic are nuclear power, mechanics of materials, numerical analysis and computing machines, steam boilers, instruments and controls, corrosion, gas turbines, pumps, piping, lubrication and welding.

ALSO OF NOTE

Fact Sheets on U. S. Nuclear Power Projects, 2nd ed., prepared by the Electric Companies Public Information Program, provides information on all U. S. projects—particularly participation by the electric utility industry. 48 pages, quantities of 10 @ $2.50. *Bozell & Jacobs, Inc., 2 W. 45th St., New York 36, N. Y.*

A Uniform Procedure for Use in the Evaluation of Nuclear Power Reactors, prepared by a Forum ad hoc committee under the chairmanship of Titus G. LeClair, presents an outline for evaluating on a common basis the performance and costs of the various reactor concepts. 44 pages, $1.50. *Atomic Industrial Forum, Inc., 3 E. 54th St., New York 22, N. Y.*

A Management Evaluation of Massive Radiation for Industrial Utilization was prepared for the AEC Office of Isotopes Development by General Aniline & Film Corp., Emerson Radio & Phonograph Corp. and Revere Copper and Brass Inc. Current, planned and foreseen uses of high-level radiation for industrial processing are surveyed. 30 pages, 75¢. *Office of Technical Services, Department of Commerce, Washington 25, D. C.*

Sixth International Congress and Exhibition of Electronics and Atomic Energy contains U. S. papers on radioactive wastes presented by the Rome meeting in June, 1959. Topics include biological implications, ultimate disposal, costs, reactor siting and meteorology. 81 pages, $2.25. *Office of Technical Services, Department of Commerce, Washington 25, D. C.*

Rare Earth Handbook, prepared by Battelle Memorial Institute, brings together physical, crystal, chemical, mechanical, electrical, magnetic, nuclear and thermodynamic data on the 15 rare-earth metals and yttrium. 214 pages, $10. *Rare Earth Research Group, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.*

Sixth Hot Laboratories and Equipment Conference (TID-7556), proceedings of the March 1958 meeting, describes the operation of various facilities, special equipment and techniques, and shielding-window design. 167 pages, $1.75. *Office of Technical Services, Department of Commerce, Washington 25, D. C.*

Effects of Nuclear Radiation on Men and Materials, by T. Charles Helvey, discusses in simple terms some of the problems presented by radiation and some possible solutions, particularly in nuclear-powered aircraft. 64 pages, $1.80. *John F Rider Publisher, Inc., 116 W. 14th St., New York 11, N. Y.*

International Directory of Radioisotopes, Vol. 1, is subtitled "Unprocessed and Processed Radioisotope Preparations and Special Radiation Sources." The Directory lists all radioisotopes for sale or distribution by major suppliers in the world (including national laboratories) and prices. Half-lives, radiations and production methods are also given. Volume 2 will list labeled compounds of C^{14}, H^3, I^{131}, P^{32} and S^{35}. 264 pages, $3.50. *International Atomic Energy Agency, Vienna, Austria (in U. S.: International Publications, Inc., 801 3rd Ave., New York 22, N. Y.).*

Selected Data on Uranium Alloys, compiled by H. C. Friedemann and H. H. Hausner, is primarily a bibliography to which are appended binary phase diagrams and some tables of mechanical-property, corrosion and irradiation data. 76 pages, $1. *Sylvania-Corning Nuclear Corp., Bayside, N. Y.*

Data Book on Physical and Engineering Properties of Materials for Nuclear Fuel Elements, compiled by H. H. Hausner, contains 80 tables of mechanical, thermal and corrosion properties of fuel and cladding materials. 55 pages, $1. *Sylvania-Corning Nuclear Corp., Bayside, N. Y.*

Nuclear Liability in Europe (AIF-CM-2) surveys European progress in providing financial protection for nuclear facilities and points up some of the defects. 24 pages, 50¢. *Atomic Industrial Forum, 3 E. 54 St., New York 22, N. Y.*

Westinghouse Periodic Chart with Nuclear Data, designed by W. E. Shoupp, is designed especially for those involved in reactor technology. The conventional format of the periodic table is retained, but some of the usual data is omitted to include more nuclear data—absorption and scattering cross sections, resonance integrals, decay energies and half-lives, fission yields and cross sections, ν and η. Several curves are also given for fission and scattering cross sections, fission yields, fission gamma and neutron spectra, and gamma shielding. $1. *Atomic Power Dept., Westinghouse Electric Corp., P. O. Box 2278, Pittsburgh 30, Pa.*

Water Supply and Pollution Control Research Inventory of Active Projects in 1958 includes many studies of radioactive-waste disposal and more conventional studies using radioactive tracers. 71 pages. *Div. of Engineering Services, Public Health Service, U. S. Dept. of Health, Education, and Welfare, Washington 25, D. C.*

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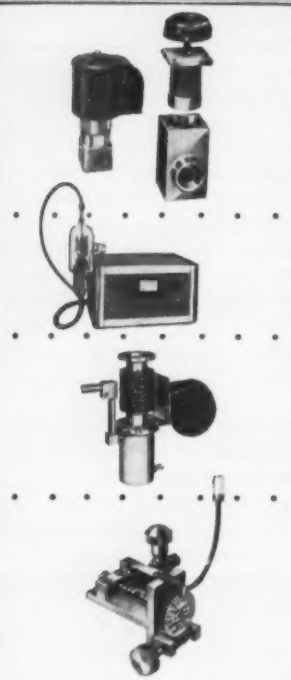

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PRODUCTS AND MATERIALS

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Abbott Labs P. O. Box 1008 Oak Ridge, Tenn.	radio-hippuran (sodium orthoiodohippurate), I^{131}
Isomet Corp. 433 Commercial Ave. Palisades, Park, N. J.	guanidine-N^{15} $N^{15}{}_2H_4 \cdot H_2O$ carbon-C^{13} (elemental form)
Isotopes Specialties Co. Div. of Nuclear Corp. of America P. O. Box 688 Burbank, Calif.	meprobamate α-amino isobutyric acid dotriacontane-1 guanidine carbonate *d*-fructose (uniformly labeled)
Merck & Co. Ltd. 560 De Courcelle St. Montreal, Canada	sodium pentobarbital-2-C^{14} β-phenylethylamine-β-$C^{14} \cdot HCl$ naphthalene-2-D_1 propane-D_8 methyl-D_3 formate
New England Nuclear Corp. 575 Albany St. Boston 18, Mass.	dimethyl-1-C^{14}-*d*-tubocurarine diiodide d-glucosamine-1-C^{14} hydrochloride d-glucose-1-C^{14}-6-phosphate, barium salt malononitrile-1-C^{14} methylcholanthrene-6-C^{14}
The Radiochemical Centre Amersham Buckinghamshire, England	4,4'-morpholide disulphide-S^{35} thiothymine-S^{35} methyl phosphonic dichloride-P^{32} thymidine (nominally T_6) *dl*-ornithine-T (G)
Schwartz Bioresearch, Inc. 230 Washington St. Mount Vernon, N. Y.	C^{14}-fructose-1, 6-diphosphate, barium
Tracerlab, Inc. 1601 Trapelo Rd. Waltham 54, Mass.	caffeine (1-methyl-C^{14}) indole-2-C^{14} trytophan, ring-2-C^{14} gramine, ring-2-C^{14} barbital-2-C^{14}
Twentieth Century Electronics Ltd. New Addington Croydon, Surrey, England	sodium borate-$B^{10} \cdot 10\ H_2O$ sodium borate-$B^{10} \cdot 5\ H_2O$ boric acid-B^{10} boron-B^{10} (elemental) boron-B^{11} (elemental)
U. S. Nuclear Corp. P. O. Box 208 Burbank, Calif.	tricresyl phosphate-P^{32} lead acetate-Pb^{210} antimony Sb^{124} (metal) carbon C^{14} (amorphous) carbon C^{13} (amorphous)
Volk Radiochemical Co. 5412 N. Clark St. Chicago 40, Ill.	colloidal chromic phosphate-P^{32} sodium o-iodohippurate-I^{131} triiodothyronine-I^{131}-T_3 thyroxine-I^{131}-T_4 Radioiodination Service*

* Samples of any material whose chemistry appears suitable are reacted by the most appropriate technique with 10 mc of I^{131}.

Specific activity (mc/mM)	*Price ($/mc)*
500 μc/mg	
	950/gm
	1,250/gm
	1,600/gm
11	1,100
4.7	450
25 mc/mM	550
49.6 μc/mg	475
0.34 mc/ml	195
1	900
1	850
98 atom % D	200/5 gm
98 atom % D	200/1
98 atom % D	250/5 gm
13.9	400
0.57	600
2.6	30 per 10 μc
1.0	450
2.55	850
10	
10	
4.4 curies/mM	
50	
2	147.50 per 100 μc vial
0.7	450
1	400
1	850
1	600
1	450
99% B^{10}	
99% B^{10}	
99% B^{10}	
99% B^{10}	
99% B^{11}	
1–100	
1–10 mc/mg	
To 4c/g	
10	
55–70%	
150	25
18	25
6000	45
7500	45
	Initial samples 100.00
	Subsequent sample 75.00

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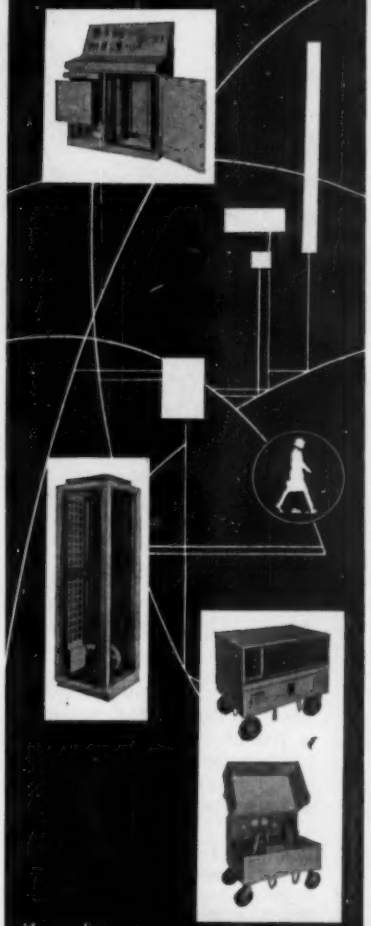
Self-contained, transformer voltage regulator (above) with no moving parts or complicated feed-back systems, automatically and continuously delivers output voltage controlled within ±1% under line voltage variations as great as ±10%. Response time is 1.5 cycles or less. Regulators are offered for three-phase circuits from 50 kva to 200 kva. Regulation is maintained during fast load changes ranging between zero load and rated load as well as simultaneous changes.—Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill.

Portable Gamma Area Monitor

Portable gamma area monitor (above) has flexibility of a survey meter plus specifications and alarm system of a fixed area monitoring installation. Rechargeable mercury battery-oper-

New technical requirements require new techniques



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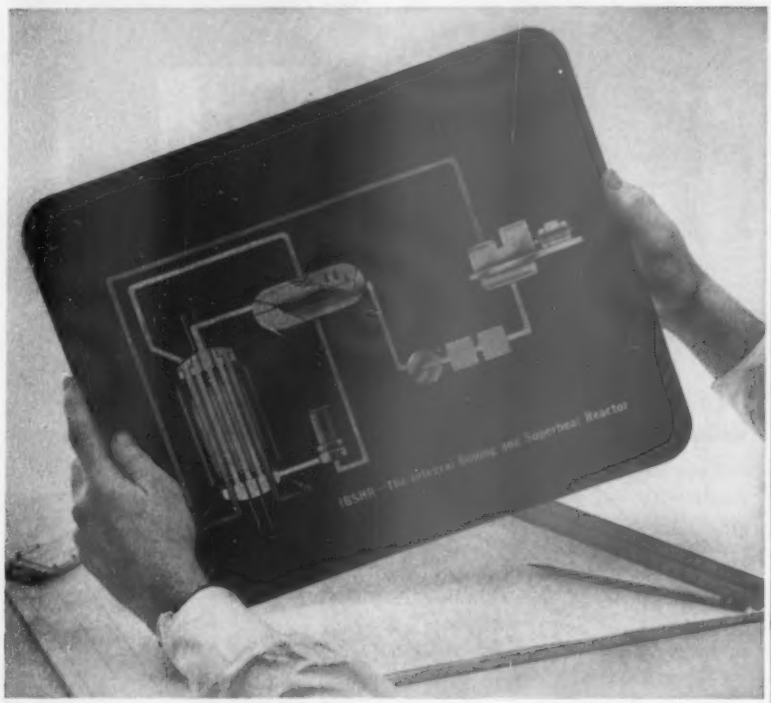

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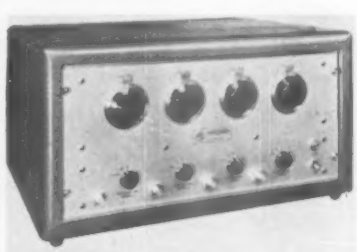
PRODUCTS & MATERIALS

Department starts on page 136

ated supply with separate rechargeable batteries operates an integral audio-visual alarm system. Up response time is .1 to 10 mr/hr in 4 sec and down time is 10 to .1 mr/hr in 12 sec.—Riggs Nucleonics Corp., 717 N. Victory Blvd., Burbank, Calif.

Automatic Sample Changers

Automatic sample changer (above) can handle and count automatically up to 200 samples. Models are available for gas flow, for scintillation, and for both. Virtually 4 pi shielding of counting chamber is provided. Information is obtained on every sample, regardless of level of activity by automatic reverting circuit which is preset at scaler. Low count samples are timed for a small fraction of full preset count.—Technical Associates, 140 W. Providencia Ave., Burbank, Calif.



Coincidence Analyzer

Model 32-2 four channel coincidence/anticoincidence analyzer (above) can be used in combination with most commercial scalers or ratemeters. It is designed for use with Geiger and scintillation detectors. Any combination of four channels can be used in antico-

incidence with any one or combination of the other three channels. Channel dead time is 10 μsec and input pulses can range from 50 v negative to 100 v positive.—Radiation Instrument Development Lab, Inc., 61 East North Ave., Northlake, Ill.

Temperature Detector

Fast-response resistance temperature detector is designed to measure reactor cooling water. It has exponential time constant of 1.5 sec and is made from a single solid piece of type "R" Monel. Temperature range is −70° C to +200° C, and max pressure can be 200 psi. Detector can tolerate radiation level of 500 rad/hr from 0° C to +170° C and radiation exposure of 5×10^7 rad total of 1 Mev average gamma radiation at temperatures of 125° C to 150° C.—Thomas A. Edison Industries, Instrument Division, West Orange, N. J.

Butterfly Valves

Stainless steel, quarter-swing butterfly valves (above) are available in 1-, 2-, 4- and 6-in. bore. All are <2 in. deep. Four- and 6-in. models can be pneumatically operated.—Edwards High Vacuum Inc., 1920 Buffalo Ave., Niagara Falls, N. Y.

Multipurpose Linear Amplifier

Multipurpose non-overloading linear amplifier accepts input pulses from 0 to 80 v. Discriminator output pulses are 15 v negative or 25 v positive. It has a gain of 10,000 and features both positive and negative B-plus.—Radiation Instrument Development Lab, Inc., 61 East North Ave., Northlake, Ill.

Glove Box

Stainless-steel controlled-atmosphere glove box can be used as a vacuum chamber by covering the glove ports with plates provided. If desired, appropriate atmosphere can be introduced into evacuated chamber with contami-

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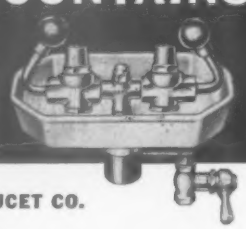

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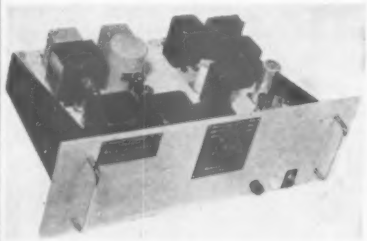
nation less than one part in 10^9 without purging. Work space is 34 in. wide × 22 in. deep × 22 in. high. Air lock can be placed on right or left side port.—Delta Design, Inc., 7460 Girard Ave., La Jolla, Calif.



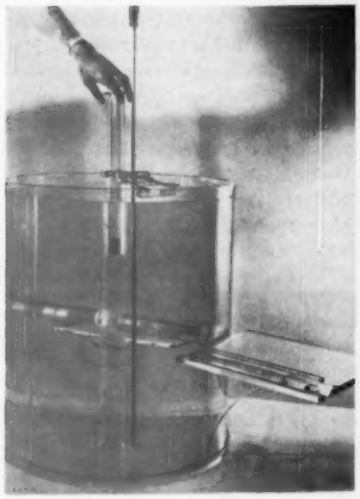
Rate of Change Computer

Rate of change computer consists of d-c preamplifier, filter with a selected roll-off characteristic followed by a rate network which develops first derivative preamplifier output. D-c impedance changer permits use of impedance by normal recorders or controllers. Units can be connected with alarm circuits and automatically initiate shutdown when set rates are exceeded. Minimum input impedance is 2.5×10^4 ohms and output impedance is 50 ohms. Six full-scale ranges between 100 and 5,000 μv/sec are provided and time constant is 0.5 sec.—Magnetic Instruments Co., Inc., Thornwood, N. Y.

Tilting-Disc Check Valves

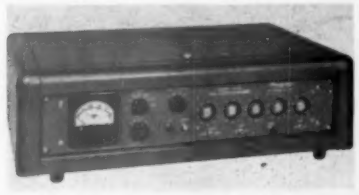
Four pumps on primary loop of N. S. Savannah are protected against coolant reverse flow by four tilting-disc check valves (above) counterweighted saucer-like disc swings on pins containing torsion springs which speed closing at moment of zero velocity while preventing alarming. Pins are mounted downstream from valve seat. Valve opens fully at flow of 8 fps. Eight similar, though larger, valves for the Indian

Point reactor will have gold-plated hinge pins and pressure-sealed gaskets for valve corners. Gold will withstand nitric acid solution specified for decontamination. Pressure-sealed gaskets in similar valves for Enrico Fermi reactor were made of pure nickel to resist liquid sodium.—Edward Valves, Inc., East Chicago, Ind.



Irradiation Facility

Neutron-gamma irradiation facility (above) is made of heavy transparent plastic and filled with distilled water. Experimental area is visible and readily accessable. Versatile facility can be used for unusual neutron experiments as well as those performed with a neutron howlitzer. Several gamma-ray experiments can also be performed. Experimental manual and visual teaching-aid kit are provided.—Reactor Experiments Inc., Box 133, Sales Mart, 1485 Bayshore Blvd., San Francisco 24, Calif.



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Compact, rack mounted, solid state G-M counting system (above) weighs only 19 lb. Scaler sensitivity is adjustable from 0.25 v to 5 v and ratemeter time constants are 0.5, 2, 10 and 40 sec. Six counting ranges are to 1×10^4 cpm max. Power supply voltage range is 350 v to 2,500 v, positive.

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Department starts on page 136

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LITERATURE AVAILABLE

Human Body Radiation Monitors. 4 pp.;

Low Level Counting Facility. 4 pp.; Nuclear Enterprises Ltd., 1750 Pembina Highway, Winnipeg 9, Canada; Bankhead Medway, Sighthill, Edinburgh, 11, Scotland.

Pipe & Tubing; Large Dia., Corrosion Resistant. 52 pp.; Swepco Tube Corp., 1 Clifton Blvd., Clifton, N. J.

High Voltage Power Supplies. 8 pp.; The Victoreen Instr. Co., 5806 Hough Ave., Cleveland 3, Ohio

Millimicrosecond Oscilloscope. Model 112, 6 pp.; Lumatron Electronics, 116–120 County Courthouse Rd., New Hyde Park, L. I., N. Y.

Nuclear Instrumentation. Bulletin GEA-7006A, 4 pp.; General Electric Co. Atomic Power Equipment Dept., 2151 S. First St., San Jose, Calif.

Temperature conversion chart. 2 pp.; Fansteel Metallurgical Corp., No. Chicago, Ill.

Nuclear fuel facility. 11 pp.; AMF Atomics Canada Ltd., Port Hope, Ontario, Canada.

Thermocouple tubing. 2 pp.; Saxonburg Ceramics, Inc., Saxonburg, Penna.

Pressure transducers. Bulletin 36010, 9 pp.; Rosemount Engineering Co.,

490 W. 78th St., Minneapolis 24, Minn.

Potentiometer transducers. 4 pp.; H. E. Sostman & Co., 347 E. Lincoln Ave., Cranford, N. J.

Resistance-type temperature detector. 2 pp.; Bailey Meter Co., 1050 Ivanhoe Road, Cleveland 10, Ohio.

Process flame photometer. 4 pp.; Waters Associates, 45 Franklin St., Framingham, Mass.

Dry box gloves. SD 60-1, 19 pp.; Charleston Rubber Co., Stark Industrial Park, Charleston, So. Car.

Periodic chart of the atoms. Atomic Development Securities Co., Inc., 1033 30th St., N. W., Washington 7, D. C.

A profile of progress - CBS electronics. 8 pp.; CBS Electronics, 100 Endicott St., Danvers, Mass.

Accurate, low-cost temperature controls. Bulletin 108, 12 pp.; Assembly Products, Inc., Chesterland, Ohio.

Scintillation transducers & crystals. 6 pp.; Levinthal Electronic Products, Stanford Industrial Park, Palo Alto, Calif.

Reactor components. Bulletin 4, 8 pp.; The Herrick & Cowell Co., 23 Devine St., No. Haven, Conn.

Eccentric valves. Bulletin 110, 8 pp.; DeZurik Corp., Sartell, Minn.

Liquid scintillation spectrometers. Bulletin 30-5/59, 4 pp.; Packard Instrument Co., Inc., P.O. Box 428, La Grange, Ill.

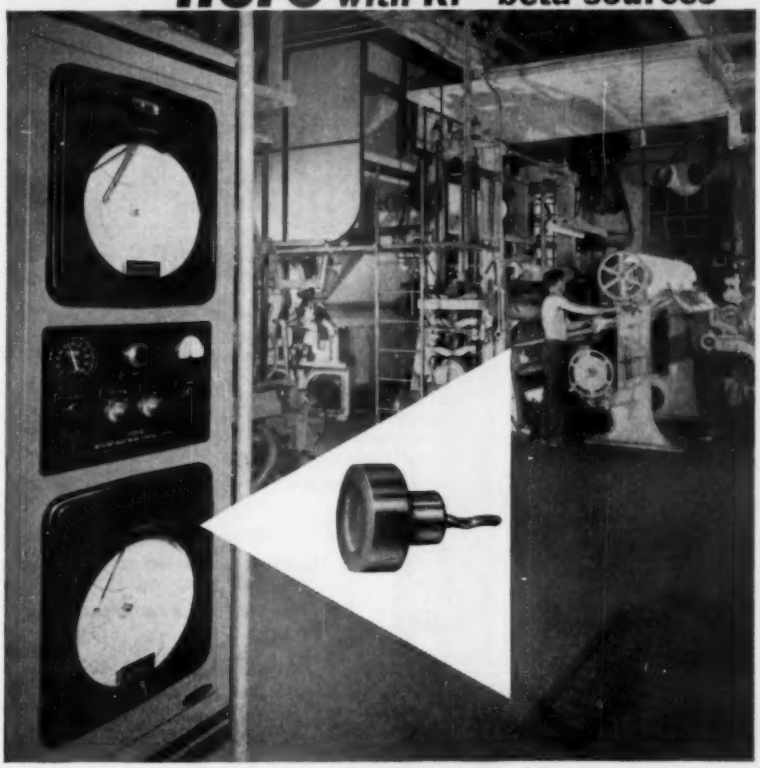
Aluminum Tube and Shapes. 30 pp.; Wolverine Tube, Div. of Calumet & Hecla, Inc., 17200 Southfield Rd., Allen Park, Mich.

Developments in Ion Exchange. Reprint 84, 12 pp.; Nalco Chemical Co., 6216 W. 66th Place, Chicago 38, Ill.

Power and Process Piping. Bulletin 60B, 24 pp.; Midwest Piping Co., Inc., 1450 S. Second St., St. Louis 4, Mo.

Plastic-Film Dust Bellows. 4 pp.; A. F.

control starts here with Kr^{85} beta sources



Regulation of basis weight by means of a beta gaging system is the key to product uniformity in this large paper plant. Control unit manufactured by The Foxboro Company utilizes a krypton-85 beta source from United States Radium Corporation—largest producer of radiation sources in this country.

This installation is one of thousands using beta, gamma and neutron sources fabricated by U. S. Radium. It is typical of the many current applications of Kr^{85} beta sources of linear or point-type design with concentrations of a few microcuries to a curie or more.

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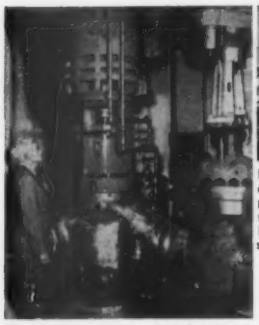
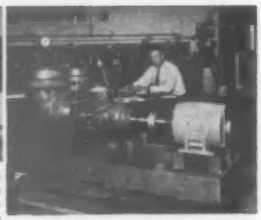


This Peerless Pump is installed at the Vallecitos Atomic Plant on the first forced circulation dual cycle boiling water reactor ever built.

Peerless has had a separate research and development group working on pumps for high temperatures and pressures since 1950. Out of this group have come pumps for atomic powered submarines, reactors, steam generators.



This limited leakage pump for an Atomic Laboratory is shown above undergoing final high temperature seal tests. Parts in contact with pumpage are all of 304 stainless steel.

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NUCLEONICS

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PRODUCTS & MATERIALS

Department starts on page 136

Gagne, Assoc., 50 Wall St., Binghamton, N. Y.

Data Translator - Paper to Magnetic Tape. 2 pp.;
Format Control Buffer for Computers. 4 pp.; Electronic Engineering Co. of Calif., 1601 E. Chestnut Ave., Santa Ana, Calif.

Armorox Thermocouples. Bulletin P1281A, 6 pp.;
Indicating Pneumatic Controllers. Bulletin DMO58, 6 pp.; The Bristol Co., Waterbury 20, Conn.

Nuclear Energy Services. 26 pp.; Gilbert Assoc., Inc., 525 Lancaster Ave., Reading, Penna.

Zirconium Data File. Zirconium Information Center, Carborundum Metals Co., Akron, N. Y.

Biochemicals & Radiochemicals. 28 pp.; Schwarz BioResearch, Inc., 230 Washington St., Mt. Vernon, N. Y.

Labeled Compound Price List. 16 pp.; New England Nuclear Corp., 575 Albany St., Boston 18, Mass.

Labeled Compounds for Research. 28 pp.; Volk Radio Chemical Co., 5412 N. Clark St., Chicago 40, Ill.

Transistor, Portable 3-In. Oscilloscope. 4 pp.; Tektronix, Inc., P. O. Box 831, Portland 7, Ore.

Recording Oscillograph. Bulletin 1623, 8 pp.; Electro Mechanical Instr. Div., Consolidated Electrodynamics, 360 Sierra Madre Villa, Pasadena, Calif.

Pressure Indicator. Bulletin F-9951, 2 pp.; Barber Colman Co., Whellco Instr. Div., Rockford, Ill.

Sliding Gate Diaphragm Control Valves. 8 pp.; OPW-Jordan, Div. of OPW Corp., 6013 Wiehe Road, Cincinnati 13, Ohio.

Butterfly Valves. Catalog 307, 4 pp.; Mason-Neilan, Div. of Worthington Corp., Norwood, Mass.

Automatic Sample Changer. 2 pp.; Radiation Instr. Development Lab., Inc., 61 E. North Ave., Northlake, Ill.

INDUSTRY NOTES

● **Nuclear Service Consultants, Inc.**, New York City, has been formed as a subsidiary of Consultants & Designers, Inc., to provide specialized consulting services to the nuclear power industry. Organizer is Edwin E. Lindahl, formerly of Bettis Atomic Laboratory, who said NSC would specialize in design problems covering the complete scope of the nuclear power plant business.

● AEC and Euratom have accepted 45 **research-development proposals** under their joint program, as of end-July. The total represents $7.8-million in research projects to be carried out by 28 Euratom and 10 U. S. organizations. Proposals accepted thus far have dealt with the fuel cycle, plutonium recycling and other general reactor areas; a new invitation for research-development on boiling-water reactors was expected during August.

● AEC has reaffirmed its policy, first announced several years ago, of refusing to accept non-AEC **neutron-irradiation business** in AEC-owned facilities unless "privately-owned facilities are not reasonably available." For the most part, AEC said, private facilities either currently or prospectively available "should be able to perform all desired commercial irradiations." Work in AEC reactors, it was stated, will be "limited to AEC projects and other projects specifically approved by AEC."

● **Industrial Uranium Co.** has filed suit against AEC, in the U. S. Court of Claims, seeking payment of nearly $1-million for vanadium produced from uranium ores at Industrial's Monument Valley, Ariz., mines. The company alleges that AEC has repudiated an agreement with the uranium industry to purchase vanadium pentoxide produced with uranium ores.

● **Isotopes Specialties div.** of Nuclear Corp. of America has appointed **C. W. Reed Co.**, Los Angeles and San Francisco, engineering representative for its line of labeled compounds and radioactive services. Reed's territory: California, Oregon, Washington, Arizona, Wyoming, Western Idaho, Montana and Nevada.

● **Natural and depleted uranium** as used in aircraft as counterweights have been exempted by AEC from its licensing regulations. In a typical application about 300 lb of U metal is used in wing tips and tail pieces of jet commercial airliners.

FINANCIAL. Its best six months since 1953 was reported by **Tracerlab** for the first half 1960; earnings were $55,000 on sales of $6,079,000, the latter up 20% from last year's first half. President S. S. Auchincloss said all company operations had shown improvement over a year ago. . . . **Hamner Electronics**, Princeton, N. J., reported 1960 sales will go beyond $800,000, as compared with $600,000 in 1959; the firm expects 1961 sales of its nuclear instruments to exceed $1-million. . . . **Cenco Instruments** is raising $5-million, through the sale of convertible debentures, to pay off $500,000 in bank loans and for possible use in increasing inventories, extending customer credit or financing acquisitions.

COMPANY MOVES. New executive offices of **Crane Co.** are: 155 N. Wacker Dr., Chicago. . . . **Combustion Engineering** has moved its general offices to Windsor, Conn., where its nuclear division has been located for five years; AEC will retain New York City offices for its chairman and chief executive officer.

ACQUISITIONS. All assets of **Anton-Imco Electronics Corp.**, New York City, have been acquired by **Lionel Corp.**; 1⅓ share of Lionel was to be exchanged for one share of Anton-Imco. . . . **Royal Industries**, Los Angeles, major supplier of control-rod mechanisms to the nuclear Navy, has acquired three California firms; one, **Dublin Industries** of San Francisco will be operated as Royal's Nuclear Science div., manufacturing nuclear-analytical systems and products for handling radioactive materials and viruses. . . . **Victoreen Instrument** has acquired **Nuclear-Electronics Corp.**, Bronx, N. Y.

NEW BUSINESS. A major construction contract for Argonne National Laboratory's Zero Gradient Synchrotron has been awarded to **Corbetta Construction Co.**, Chicago; Corbetta bid $4,288,400 for constructing two ZGS buildings and a system of concrete tunnels above grade.

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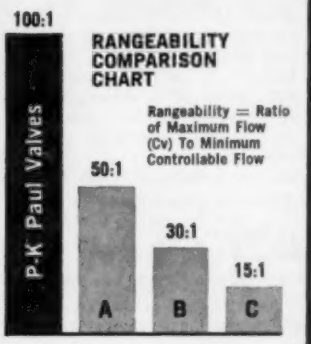

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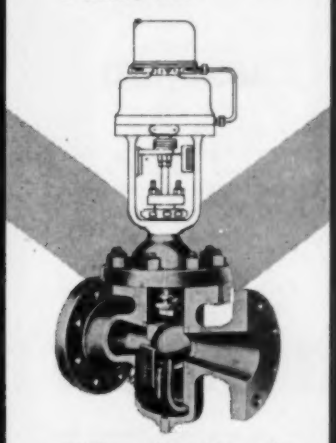

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NEWSMAKERS

John C. Bugher has reported to the Caribbean as director of the Puerto Rico Nuclear Center. In a distinguished nuclear career, Bugher has been consultant on nuclear energy affairs at the Rockefeller Foundation, director of AEC's Biology and Medicine div. and chairman of AEC's Advisory Committee for Biology and Medicine.

Chief of the government's NS *Savannah* project, **Preston Eddy,** has left AEC and the Maritime Administration (he wore two hats) to join General Electric's Atomic Power Equipment dept.

David F. Shaw has been named general manager of General Electric's Aircraft Nuclear Propulsion dept., which has recently been made part of GE's Flight Propulsion div. Shaw took his new post from H. J. Kaiser Co., where he had been vice-president of engineering. **Samuel J. Levine,** manager of ANP's Projects section, had taken the post on an acting basis earlier this year from **Roy Shoults,** now in GE's New York City Office.

Shaw

AEC has appointed a second hearing examiner. He is **J. D. Bond,** formerly of the Federal Communications Commission, who joins Samuel W. Jensch.

Sherwood L. Fawcett has been appointed manager, Physics dept., Battelle Memorial Institute, succeeding the late H. R. Nelson (NU, June '60, 158). Fawcett had been assistant of the department, which includes more than 300 scientists, engineers and technicians in nuclear and solid-state physics and reactor technology, since 1957.

Fawcett

A British plasma and electron-dynamics specialist, **Oscar Buneman** of Cambridge Univ., has joined Stanford Univ.'s Electronics Laboratories as senior research associate and lecturer in electrical engineering. He will devote much of his time to research on the limitations on current flow in plasmas. Before joining Cambridge in 1950, Buneman had been senior principal scientific officer at the U. K.'s nuclear research center, Harwell.

Atomics International has appointed its manager of applications engineering, **Robert L. Loftness,** to represent AI in the management of Dynatom, the firm's new French affiliate; Loftness will be commercial director of Dynatom. The other officers are: president, **Joseph-Auguste Laurin;** and vice-president and deputy to Laurin, **Roger Julia,** director general of Societe Alsacienne de Constructions Mecaniques, one of AI's two French partners in the venture. At AI's Canoga Park, Calif., headquarters, **Raymond J. Beeley** has been named deputy director of the Sodium Reactors dept. and **James E. Mahlmeister** has succeeded Beeley as group leader, sodium reactor engineering.

Loftness

Radiation Dynamics, Inc., has named **Karl Eklund** director of research and applied ion physics. Eklund joined RDI from Columbia Univ., where he worked on electron and gamma-ray spectroscopy (associated with charged particle reactions) in the Pegram Nuclear Physics Laboratories. Eklund is expected to have a major role in RDI's development of advanced accelerators.

Eklund

Stanley Grand, former director of research and development at Radiation Research Corp., has joined Vitro Laboratories, West Orange, N. J., as head of the Chemistry and Arc Research dept.

Chief of the Mass Spectrometry section, National Bureau of Standards—**Fred L. Mohler**—has retired after 43 years with the Bureau.

Walter A. Hamilton, a member of the Robert McKinney staff during McKinney's recent international-atomic-energy study for the Joint Committee

on Atomic Energy, has returned to his post as contracts director, Nuclear Development Corp. of America.

Three management changes at AEC's General Electric-operated Hanford Works: **R. L. Dickeman** has been named general manager, Fuels Preparation dept.; **L. L. German,** manager, Construction Engineering and Utilities operation; and **O. C. Schroeder,** manager of manufacturing, Irradiation Processing dept.

AEC's New York Operations Office has elevated **Carl R. Stahle** to director of the Reactor div. from his former post as chief of the Development branch.

A former official of AEC's Reactor Development div., **Don B. Coburn,** has joined General Atomic div. of General Dynamics as a member of the research staff, where he will work in the area of advanced-reactor concept evaluation. Coburn was chief of the High Temperature Reactors branch at AEC before he went to GA; he was also first chairman of the new-concept selection board, which has been dissolved.

Coburn

Wesley A. Funk has left his post as deputy manager of AEC's Idaho Operations Office to join the International Cooperation Administration; his first assignment for ICA will be as engineering advisor to the Korean government.

New staffers at Armour Research Foundation: **Daniel Sperber,** associate physicist in reactor physics; **Gene H. Wojciechowski,** assistant physicist in solid-state physics; and **John Reed** and **John Palsedge,** assistant physicists in nuclear physics.

Geoffrey G. McKenzie has been named controller at AMF Atomics, Canada; he had been chief internal auditor. McKenzie is also an organizer of the projected Canadian nuclear industry association.

Robert H. McCulloh, manager of AEC's Portsmouth Area Office, has retired. A 12-year AEC veteran, McCulloh is joining American Machine and Foundry Co. at Marysville, Calif.

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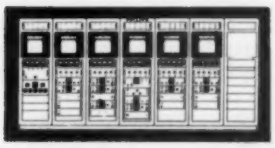
no living on a volcano



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NUCLEAR CALENDAR

Sept. 7–9—First Joint Automatic Control Conference, sponsored by Instrument Society of America, American Institute of Chemical Engineers, American Institute of Electrical Engineers, American Society of Mechanical Engineers and Institute of Radio Engineers, Cambridge, Mass. (*Massachusetts Institute of Technology*). Contact James Mozley, Johns Hopkins Univ., Baltimore, Md.

Sept. 11–16—138th National Meeting of American Chemical Society, New York (*Statler-Hilton*). Nuclear Technology subdivision of ACS' Division of Industrial and Engineering Chemistry will sponsor two programs: Sept. 15, nuclear-fuel materials and chemical processing of irradiated fuels; Sept. 16, recovery of useful fission products and transuranic elements. Contact C. E. Stevenson, Argonne National Laboratory, P.O. Box 2528, Idaho Falls, Idaho.

Sept. 13–16—Fifth Instruments and Measurements Conference, Stockholm, Sweden (*Royal Institute of Technology*). Includes section on nuclear instrumentation. Contact Helge von Koch, Royal Inst. of Tech., Stockholm, 70.

Sept. 26–30—Fall Instrument-Automation Conference and Exhibit and 15th Annual Meeting of Instrument Society of America, New York City (*Coliseum*). Contact W. H. Kushnick, ISA, 313 6th. Ave., Pittsburgh 22.

Sept. 27–30—Power Systems Conference, American Rocket Society, Santa Monica, Cal. (*Miramar*). Full day on systems for auxiliary nuclear power (SNAP). Sponsored by Air Force, Army, Navy, AEC, and NASA. Contact Nathan W. Snyder, Institute for Defense Analysis (ARPA div.), Universal Bldg., Washington, D. C.

Oct. 3–5—Seventh Annual National Meeting of Professional Group on Nuclear Science, Institute of Radio Engineers. Featuring nuclear applications of solid-state detectors and low-noise amplifiers. Fifty-word abstracts are due Aug. 1. Contact H. E. Banta, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tenn.

Oct. 4–5—Symposium on Physics and Nondestructive Testing, Argonne National Laboratory, Argonne, Ill. Emphasis on physical principles rather than on application, with special appeal to those working on new and improved techniques. Contact W. J. McGonnagle, ANL, 9700 S. Cass Ave., Argonne, Ill.

Oct. 12–14—Combined meeting: Fourth Conference on Analytical Chemistry in Nuclear Reactor Technology, and First Conference on Nuclear Reactor Chemistry, sponsored by Oak Ridge National Laboratory, to be held concurrently, Gatlinburg, Tenn. Ana-

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Sept. 17–21—Symposium on Neutron Pile Research, Vienna.

Oct. 11–14—Symposium on Inelastic Scattering of Neutrons in Solids and Liquids, Vienna.

Oct. 17–22—Symposium on Diagnosis and Treatment of Acute Radiation Injury, Geneva.

Oct. 24–27—Symposium on Chemical Effects of Nuclear Transformation, Prague, Czech.

Nov. 14–18—Symposium on Nuclear Ship Propulsion (special reference to safety), Italy.

Dec. 5–9—Symposium on Pest Control by Radiation, India. On all IAEA meetings, contact John Burt, IAEA, United Nations, N. Y.

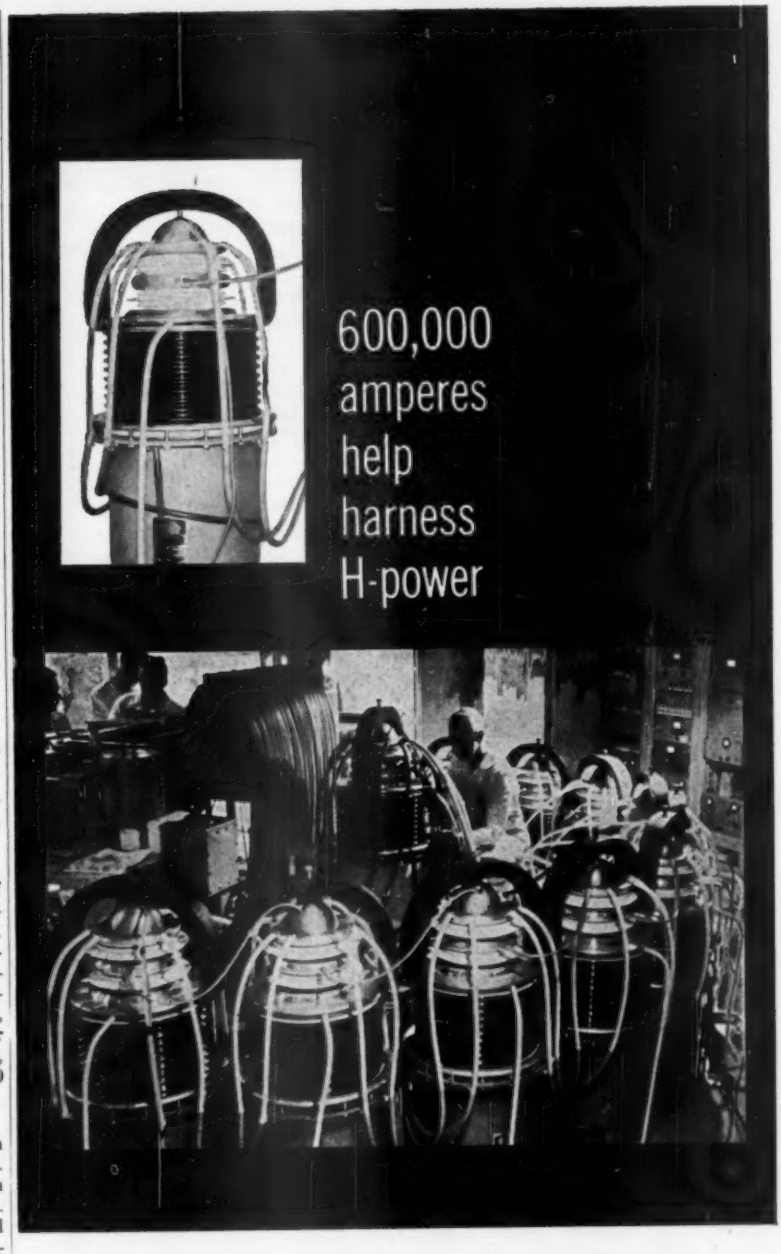
lytical Chemistry meeting focus on instrumentation and methods for determination of minor and trace components in fuels, coolants, moderators; Chemistry meeting will stress chemical behavior of reactor materials rather than engineering applications. Contact: (for former) C. D. Susano, (for latter) W. R. Grimes, ORNL, Box Y, Oak Ridge, Tenn.

Oct. 24–26—Symposium on Medical and Biological Aspects of the Energies of Space, San Antonio, Tex. (*Granada*). Contact Jack Harmon, Southwest Research Institute, 8500 Culebra Rd., San Antonio.

Nov. 28–Dec. 2—Annual Meeting of American Society of Mechanical Engineers, New York City (*Statler-Hilton*). Concurrently 24th National Exposition of Power and Mechanical Engineering (*Coliseum*). For ASME, contact A. Bruce Conlin, Jr., ASME, 29 W. 39th St., New York City; for exhibition, contact E. K. Stevens, International Exposition Co., 480 Lexington Ave., New York 17, N. Y.

Dec. 5–8—Annual Meeting of American Rocket Society, Washington, D. C. (*Shoreham*). Unclassified session on nuclear rockets; abstracts due Aug. 15. Contact Frank Rom, Aeronautics and Space Administration, Lewis Research Center, 21000 Brookpark Rd., Cleveland, Ohio.

Dec. 11–16—American Nuclear Society–Atomic Industrial Forum joint meeting, San Francisco (*Mark Hopkins* and *Fairmont*). 12–15th Atomfair West, first West Coast nuclear industrial exposition (*Masonic Memorial Building*). Contact W. Kelly Woods, Vallecitos Atomic Laboratory, Pleasanton, Calif., for ANS program; Edwin Wiggin, AIF, 3 E. 54 St., N. Y. 22, for Forum program; Dan Scherer, AIF, for Atomfair. 11–14—8th Hot Laboratory and Equipment Conference. Paper summaries due May 16. Contact James R. Lilienthal, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, N. M.



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Address inquiries to: R. N. Killelea, Manager, Professional Recruiting, Nuclear Division, Combustion Engineering, Inc., Windsor, Connecticut.

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NUCLEAR CAMPUS

CAMPUS FACILITIES. The Board of Regents, **Univ. of Michigan,** has approved a start this summer on a $1.1-million cyclotron laboratory; the 40-Mev cyclotron to go into the lab will be purchased with AEC grant funds . . . . Both **Duke Univ.** and the **Univ. of Washington** have plans to install linear accelerators on campus. Duke will order a 3-Mev Van de Graaff—its second—for delivery next year, with funds available under two renewed contracts with AEC (totaling $398,000). Washington has scheduled acquisition of a linac under an $18-million improvement program during the school's 1961–63 biennium. . . . Convair div. of General Dynamics will build a 10-kw teaching reactor for **Texas Technological College;** the reactor will be located in a projected Nuclear Reactor and Chemical Engineering Building, scheduled for construction within the next few years. . . . **Northwestern, Cornell** and **Pennsylvania** have been selected by the Defense dept.'s Advanced Research Projects Agency as sites for materials-research centers. ARPA is making multi-million-dollar contributions to the cost of constructing the centers and will make significant contributions to operating expenses.

● **California Institute of Technology** and **Georgia Tech Engineering Experiment Station** have recently been awarded AEC research and/or equipment funds: Cal Tech will use most of a $24,000 grant to build a heat transfer loop for the investigation of transfer rates and in training graduate students; Georgia Tech, under a $99,392 contract, will conduct solid-state research, beginning with a study of surface properties of magnetic materials.

COURSES. A technical training program prepared by the General Motors Institute for teaching GM professional people the basics of **radioisotope applications** has been made available for sale through the Office of Technical Services, U. S. Department of Commerce. The two-volume course (Radioisotopes in Industry—Training Program) is $10.

Taft Sanitary Engineering Center, Cincinnati, is offering **radioactive pollutants in water,** Nov. 7–11; **radionuclides in water,** Nov. 14–18; and **chemical analyses for water quality** and **medical aspects of radiological health,** both Nov. 28–Dec. 9.

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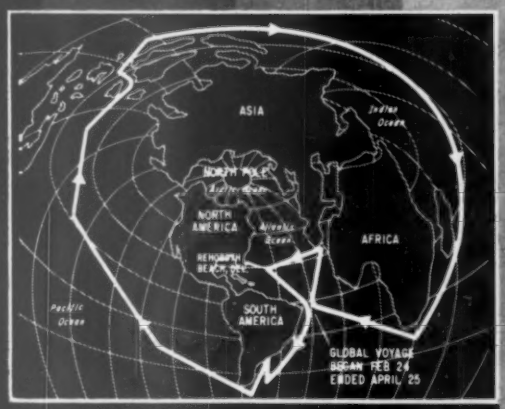

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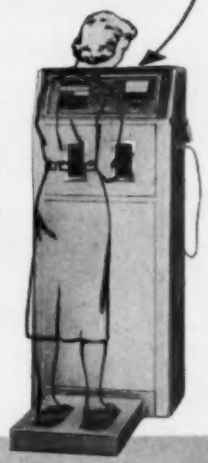

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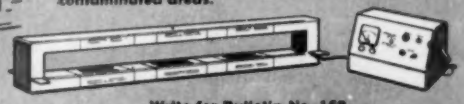

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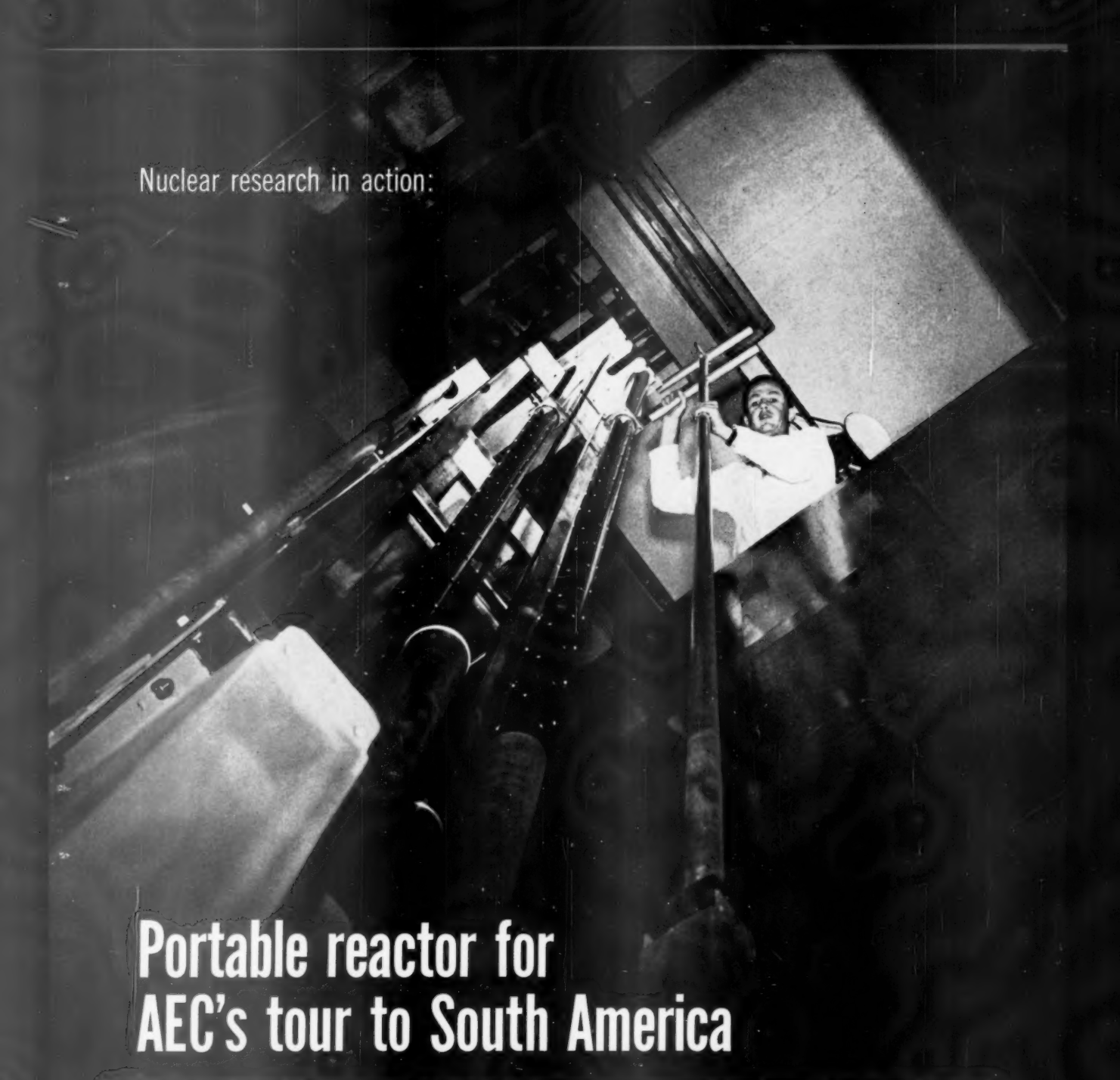

Nuclear research in action:

Portable reactor for AEC's tour to South America

When the Atomic Energy Commission's *Atoms at Work* exhibition is opened to the public at the Argentine Sesquicentennial Exposition in Buenos Aires in November, a major attraction will be the Lockheed-built nuclear reactor. It is a relatively high-powered training reactor capable of performing a wide range of experiments and demonstrations. The entire reactor—tank, control rod drives, instrumentation system, and console—breaks down into compact units for easy shipment. This is the first pool-type reactor that has been specifically designed and built for easy assembly and disassembly. Buenos Aires is the first stop on AEC's extended tour of South America. *Address: 3272 Peachtree Road, N. E., Atlanta 5.*

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